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Geologic Ground-Truth Inventory of Liberty Bell, Western Bonnifield Mining District Geophysical Survey Tract

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INTRODUCTION

The Liberty Bell project is part of DGGS's Airborne Geophysical/Geological Mineral Inventory (AGGMI) program, a special multi-year investment by the State of Alaska to expand Alaska's geologic and mineral resources knowledge base, catalyze future private-sector mineral exploration and development, and guide state planning. The program seeks to delineate mineral zones on Alaska state lands that: (1) have major economic value; (2) can be developed in the short term to provide high-quality jobs for Alaska; and (3) will provide diversification of the State's economic base. The AGGMI program, which received initial funding in FY93, was originally designed to systematically acquire geophysical and, where necessary, geological data for about 40 million acres of state-owned lands having high perceived mineral potential. Funding limitations in the past have led to decreasing the annual scope of the project, but the purpose and goals have not changed. To date more than 6.1 million acres of state-owned lands have been surveyed. As a result of this program, millions of dollars of venture capital have been spent in the local economies of the surveyed mining districts and adjacent areas in direct response to the new geologic knowledge provided by the surveys.

The Airborne Geophysical/Geological Mineral Inventory program is designed to coordinate the generation of airborne geophysical data with ground-based geological surveys. Geophysical data are of limited effectiveness unless good geologic maps are available to permit analysis and interpretation of the geophysics. The geophysical data and follow-up ground-truth geologic mapping stimulates increased mineral exploration investment within survey areas and the surrounding region. After release of the geophysical data, DGGS's Minerals Section geologic mapping team produces 1:63,360-scale or 1:50,000-scale geologic maps of the geophysical tracts; typically a bedrock-geologic map and also frequently surficial-, comprehensive- (merged bedrock- and surficial-geologic map), and engineering-geologic maps are produced for a given area. The principal objective is to catalyze industry exploration for mineral deposits. Should mineral development occur, surficial- and engineering-geologic data generated by this project will be useful for mine site and access planning.

Funding for the geophysical data is provided by the Alaska State Legislature. Funding for the geologic ground-truthing of each geophysical area comes from the Alaska Airborne Geophysical/Geological Mineral Inventory program, the State's General Fund, and the Federal STATEMAP program. Geologic mapping in the Liberty Bell area is the most recent ground-truth mapping project associated with the AGGMI program.

PROJECT FOCUS

DGGS released airborne magnetic and electromagnetic geophysical maps for 276 square miles near Liberty Bell, western Bonnifield mining district, in March 2002. During the summer of 2005, DGGS conducted fieldwork for 21 days, covering 131 square miles of the Liberty Bell geophysical survey tract coinciding with the southern half of the Fairbanks A-4 Quadrangle. The objective of the Liberty Bell project is to produce a 1:50,000-scale geologic map to foster a better understanding of the geology and mineral potential of the area. Although the Liberty Bell project team is concentrating on characterizing plutonic-related gold and associated mineralization, the team is also studying Tertiary sedimentary deposits, which contain coal resources. In addition to field traverses, the geologic map incorporates interpretations of airborne geophysical data (Burns and others, 2002) and is supplemented by ore-element geochemical analyses, coal energy and trace-element analyses, major- and minor-element analyses, $^{40}Ar/^{39}Ar$ and possible pollen age determinations, thin section and grain mount petrography, Tertiary clay compositions determined by X-ray diffraction, and historical and mineral industry data. Data from ore-element geochemical analyses and major-, minor-, and trace-element analyses were published in October 2005 (see "New Publications" section in this newsletter).

The Bonnifield district is located about 80 miles south of Fairbanks and extends across the north flank of the Alaska Range for approximately 40 miles. The western part of the district is highly accessible, with extensive infrastructure for mineral development (fig. 1). Alaska's main ground transportation corridor between Anchorage and Fairbanks, containing

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the Parks Highway and Alaska Railroad, runs 5 miles from the border of the study area. A well maintained, 10-mile-long dirt road (informally known as the Ferry Road) and numerous spur trails exist between the Liberty Bell Mine near the center of the map area and Ferry, Alaska, a small community situated adjacent to the railroad. Beside the same transportation corridor, two high-voltage interties connect the Healy Power Plant (located 12 miles south of the map area) to the power grid that provides electricity to Fairbanks, Anchorage, and numerous railbelt communities.

Approximately 85,000 ounces of placer gold have been mined from the region since 1903 (Szumigala and Hughes, 2005), with most production between the Totatlanika River and Ferry. Eleven placer gold mines (three active) and eight metallic lode occurrences are located in the map area (Freeman and Schaefer, 2001) (fig. 2). The Liberty Bell gold mine is the major lode occurrence known in the mining district. The Liberty Bell property has an announced potential of 250,000 ounces of gold, with inferred resources of 1,240,000 tons at an average grade of 0.1 ounces of gold per ton at the Mine Zone (Freeman and Schaefer, 2001).

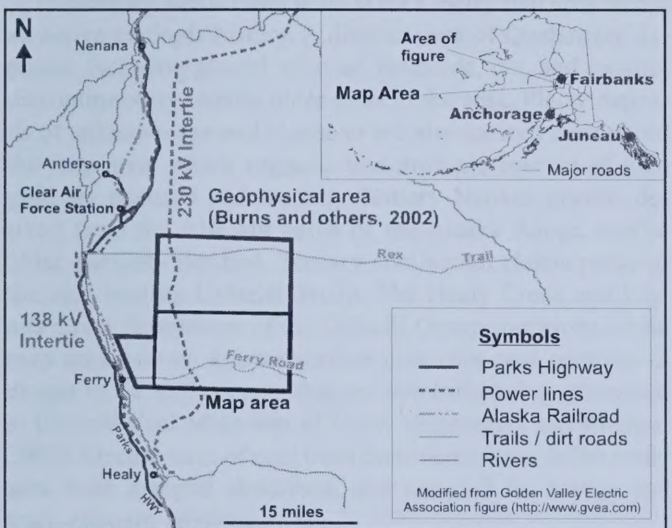

Figure 1. *Location of the Liberty Bell project geologic map area.*

PREVIOUS GEOLOGIC WORK

The Liberty Bell Mine was discovered in 1915 and actively mined during 1932–33, producing a total of 8,400 ounces of gold (Yesilyurt, 1996). The property was purchased by Boyd Blair in 1964, and his estate is currently held in a trust. Since 1973, the Liberty Bell area has been evaluated by more than five exploration companies. A wealth of private information centered around the Liberty Bell Mine is held by companies and individuals, including but not limited to data for more than 33 diamond drill holes totaling 11,706 feet, 28 reverse-circulation drill holes totaling 6,794 feet, surface sampling, and trench and conventional geologic mapping (Yesilyurt, 1996). A Master of Science thesis on the Liberty Bell property commissioned by the mineral industry was completed by Suleyman Yesilyurt in 1993 (Yesilyurt, 1994). DGGS has access to most of the private mineral industry data and will incorporate it into the geologic map and ore-genesis interpretations.

The only published geologic map covering the Fairbanks A-4 Quadrangle is one sheet of a 1:63,360-scale series concentrating on the stratigraphy immediately north of the Alaska

◇ ARDF Lode Occurrences

■ ARDF Placer Gold Occurrences

– – Generalized boundary of Tertiary and mid-Paleozoic units

Figure 2 . *Geology of the study area after Wahrhaftig (1970b). Gold and polymetallic lode occurrences and gold placer occurrences from Alaska Resource Data Files (ARDF; Freeman and Schaefer, 2001).*

Range (Wahrhaftig, 1970b) (fig. 2). Wahrhaftig's (1968, 1970a–e) Quaternary, Tertiary, and Paleozoic geologic units are broadly defined and frequently mapped as undifferentiated or queried. The maps do not address details of internal stratigraphy, contact relationships, or resources and contain little to no structural interpretation. Modern 1:50,000-scale geologic mapping will provide a more detailed geologic framework to guide mineral exploration efforts, aid in interpreting the recently acquired geophysical data, and afford new insights into plausible regional geotectonic models.

DGGS Geologic Investigations in the Liberty Bell Area

Quaternary and Tertiary units in the Liberty Bell area record an active geologic history. A diverse suite of Quaternary deposits, including glacial, alluvial, landslide, fan, and swamp, discontinuously overlie older units in the area. Placer deposits of unknown age and character are also located throughout the map area, which suggests that multiple sources of lode gold are exposed and eroding. Tertiary Nenana gravels derived from the <10 Ma uplift of the Alaska Range overlie older, partially lithified, Tertiary continental clastic rocks of the coal-bearing Usibelli Group. The Healy Creek and Lignite Creek formations of the Usibelli Group southwest of the map area contain known surface mineable coal reserves in excess of 80 million tons that are currently being processed at Usibelli Coal Mine east of Healy (Szumigala and Hughes, 2005). Occurrences of coal from these formations in the study area were mapped, described, and sampled for energy and trace-element analysis.

Bedrock, exposed and underlying the Quaternary and Tertiary units in angular unconformity, is mapped by Wahrhaftig (1970b) as two greenschist-facies meta-igneous and metasedimentary rock formations, Totatlanika and Keevy Peak (fig. 2). The Keevy Peak Formation, located stratigraphically below the Totatlanika schist, regionally contains quartz–sericite schist, carbonaceous schist, gray–green–purple slate, black quartzite, and stretched conglomerate (Wahrhaftig, 1968). In the map area, the Keevy Peak Formation contains phyllitic quartzite and carbonaceous phyllite. Locally exposed, thinly cyclic, size-graded quartzite–phyllite layers indicate in part a deep-water, turbidite origin.

Wahrhaftig (1968, 1970b) designated five members of the Late Devonian to early Mississippian Totatlanika schist (U-Pb zircon age; Dusel-Bacon and others, 2004); the lower two are present in the map area. The lower Moose Creek Member contains carbonaceous schist, green chloritic schist, and quartz–orthoclase schist/gneiss (Wahrhaftig, 1968). The aerially extensive and stratigraphically younger California Creek Member, which hosts the Liberty Bell gold deposit, contains a variety of metamorphosed volcaniclastic and sedimentary rocks. Wahrhaftig distinguished the lowest (Moose Creek) member from the stratigraphically higher California Creek Member based on color (yellow vs. gray) of the felsic meta-igneous rocks, considered the contact between the members an unconformity, and suggested that both units consisted primarily of crystal-rich metatuff.

Our mapping shows that felsic meta-igneous rocks from both 'members' vary in color; texturally and chemically, they are indistinguishable from each other. The same analyses indicate that the meta-igneous rocks are variably porphyritic metagranite intrusions or rhyolitic volcanic rocks (shallowly emplaced and [or] extrusive). The lower ('Moose Creek') felsic meta-igneous rocks contain local inclusions of the underlying Keevy Peak Formation. We interpret the variable thickness of this lower 'member' to be a result of its igneous nature. In contrast, we have identified a unit of mixed lithologies, historically mapped as a part of the California Creek Member, that does have stratigraphic significance. This unit, consisting of metaclastic rocks, rhyolitic tuff, and calcareous metabasite, is approximately 330–650 feet thick and traceable across the area for at least 15.5 miles (fig. 3, dark purple- and dark blue-colored units). Due to its abnormally high carbonate content, this unit is the preferred ore host in the Liberty Bell area. Because the unit only contains anomalous metals where hornfelsed, the metals were likely sourced by a pluton during its emplacement.

The bulk of the California Creek Member is meta-graywacke (probably volcaniclastic in origin), meta-arkose, meta-sandstone, and porphyritic to equigranular metagranite with lesser metarhyolite tuff. The felsic meta-igneous rocks contain high Nb+Y values, consistent with an extensional setting; rare metabasite similarly displays within-plate trace-element compositions. The combination of mostly felsic (porphyritic dacite and rhyolite, and aplite) and occasionally mafic sub-units indicates an ancient, bimodal volcanic system. The bimodal chemistry, elevated concentration of high-field-strength and rare-earth elements, and presence of carbon-rich basinal sediments suggest that these rocks formed in an extensional tectonic setting such as an attenuated continental margin (Dusel-Bacon and others, 2004).

Both the Totatlanika and Keevy Peak schist formations are associated with volcanogenic massive sulfide (VMS) occurrences (commonly containing galena + sphalerite ± chalcopyrite ± pyrite); the closest occurrence is located about 7 miles southeast of the map area in the central Bonnifield mining district (Wahrhaftig, 1970c; Freeman and Schaefer, 2001; Ellis and others, 2004). No stratabound base-metal sulfide occurrences were located during the recent mapping project. We currently interpret the absence of volcanogenic massive sulfide prospects in this portion of the Totatlanika schist to be a result of the scarcity of volcanic rocks; the center of the ancient volcanic system was possibly tens to hundreds of miles away, and (or) it occurred later (higher in the stratigraphic section).

Gold mineralization is associated with unfoliated, Cretaceous quartz–feldspar porphyritic bodies that intrude the mid-Paleozoic metamorphic units (Yesilyurt, 1996; Dusel-Bacon and others, 2004). This study determined that many more felsic dikes and mineralized veins occur in the field area than are shown on the published map of the quadrangle (Wahrhaftig, 1970b). Mineralization in the study area primarily includes arsenopyrite ± gold ± bismuth minerals ± tourmaline + quartz veins and replacements, and pyrrhotite ± gold ± arsenopyrite + actinolite + biotite skarn (this study; Yesilyurt, 1996). Cu-,

Sb-, Pb- and Zn-bearing ore minerals are associated with gold–arsenopyrite mineralization and (or) are present as distal expressions of Au–As–Bi mineralization. Enriched gold values are associated with potassium silicate (alkali feldspar–biotite–tourmaline–quartz), chlorite–sericite–quartz, and widespread quartz–sericite alteration assemblages (Yesilyurt, 1996). Secondary biotite and sericite from altered rocks yield ~92 Ma ages (K-Ar, 91.6 ± 0.9 and 93.0 ± 1.0 Ma, respectively; Yesilyurt, 1996). The nearby granitic intrusions, potential sources of mineralizing fluids, are usually composed of altered, reduced, porphyritic to rarely equigranular (± biotite) granite and minor hornblende–biotite granodiorite and tonalite. Pending Ar-Ar ages from the intrusions, if similar to the ~92-million-year age of alteration, will show that the intrusions are an intrinsic part of Liberty Bell's plutonic-related mineralized system. Liberty Bell mineralization has the same general age, chemistry, and character seen in Tintina gold belt plutonic-related gold systems.

Evidence of recent igneous activity is found in and adjacent to the study area. Wahrhaftig (1970a–e) mapped numerous Tertiary(?) basalt, diabase, andesite, and rhyolite bodies in the quadrangles adjacent to the Fairbanks A-4. Two Holocene maars, vesicular basalt erupted into the water table, are exposed as pond-filled craters 3 miles east of the map area (age from radiocarbon-dated charcoal; Albanese, 1982). Jumbo Dome, located 1.5 miles south of the map area, is a 2.8 Ma hornblende dacite body (K-Ar age; Wahrhaftig, 1970d). New Ar-Ar ages and chemistry of dacite flows in the southeastern corner of the map area (fig. 3, magenta-colored units) and gabbro dikes to the north may extend the Jumbo Dome volcanic rocks north or indicate a period of igneous activity previously unrecognized in this area.

A complex system of dormant and active faults displaces the geologic units discussed above. It is clear that the structural picture for the region is considerably more complex than shown on the previously published map. Recent regional and primarily photogeologic studies suggest that the northern Alaska Range foothills are actively undergoing compression, resulting in a wedge-shaped fold and thrust fault belt propagating north from the Alaska Range (Thoms, 2000; Ridgway and others, 2002; Bemis, 2004). Because important Alaskan infrastructure traverses the Northern Foothills thrust, and national defense facilities are located nearby, one of the objectives of DGGS's Liberty Bell project was to collect data that could help provide a better understanding of the regional tectonic framework. Through detailed surficial and bedrock mapping and interpretation of linears in the electromagnetic and magnetic geophysical data (Burns and others, 2002) and aerial photography, we recognize sets of high-angle faults with differing orientations (northwest-, northeast-, and east–west-trending) and relative ages that truncate geologic units and mineralization. Our geologic mapping found no evidence of the postulated thrust faults in the map area. If present, the near-surface expression of this basement-involved, regional

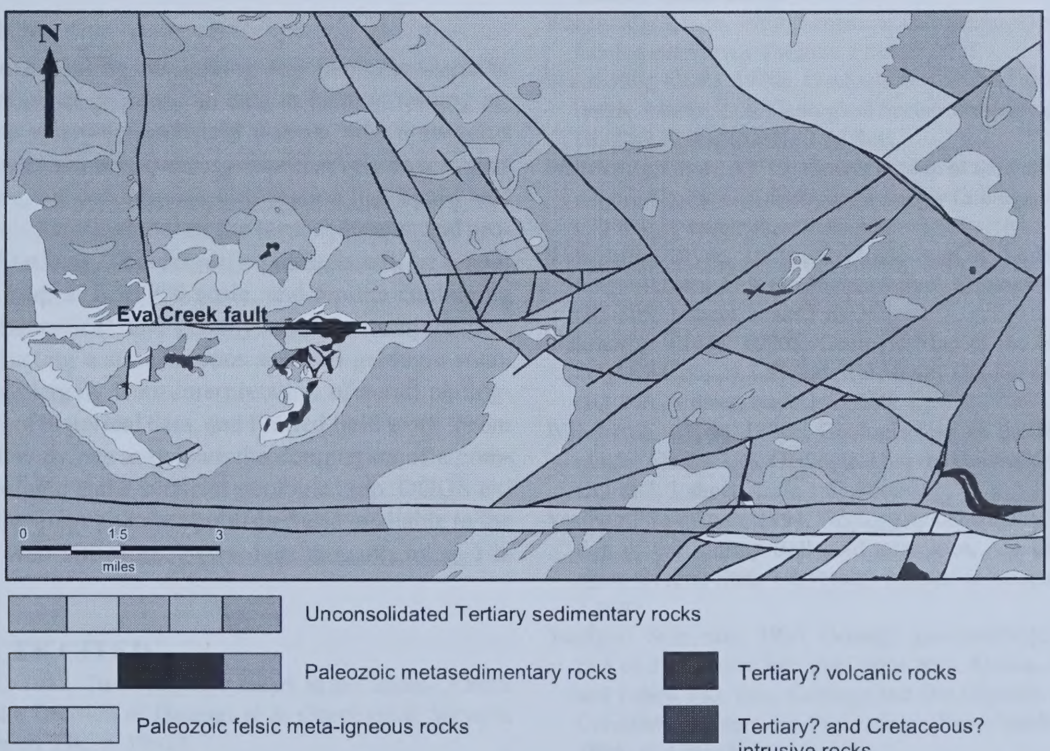

Figure 3. *1:50,000-scale draft geologic map of the Liberty Bell area (this study). Pending Ar-Ar ages from unmetamorphosed igneous rocks will help to define periods of igneous activity in this area and allow comparison with other igneous rocks in the Interior, specifically plutons associated with the Tintina Gold belt, and south of the study area.*

structural system may be either active in conjunction with, superimposed on, or possibly reactivating high-angle faults.

Of particular interest is the Eva Creek high-angle (70–90°) fault, which displaces mineralization and hornfels in the Cody Creek–Liberty Bell Mine area (fig. 3). Plots of ore-element concentrations from rock samples suggest that relative movement on this fault is south-side-up; Te and Cu, elements found more proximal to plutons in hydrothermal systems, are concentrated south of the fault while Sb, Pb, and Zn, elements found more distal to plutons in hydrothermal systems, are more concentrated to the north of the fault. This elemental evidence suggests a possible vertical offset of more than a thousand feet. Mapping from this study and Freeman and others (1987) noted the opposite sense of movement on a section of this fault in the Liberty Bell Mine area; the fault is north-dipping and south-side-down (reverse), and several hundred feet of offset is indicated. Either the Eva Creek fault has been later reactivated within a different stress regime or the fault is actually composed of several en echelon faults with different directions and amounts of offset. This fault is important because it offsets a 4.5-mile-wide magnetic high mapped as pyrrhotite-bearing hornfels and the ore-element geochemical anomalies discussed above. Small, scattered intrusions are unlikely to have provided enough heat to produce the high volume of hornfelsed rock. The offset hornfels ring and geophysical signatures indicate the hornfels surrounds a buried pluton, suggesting the potential existence of a large mineralized system at depth.

CONCLUSION

DGGS believes that by conducting new geologic mapping with interpretation of geophysical data in historic mining areas such as the western Bonnifield district, which contains lode gold deposits and occurrences with relatively easy access to infrastructure, we will provide information that could lead to mineral development, stimulate the local economy, and provide jobs for Alaskans. This project's products will be a bedrock-geologic map at 1:50,000 scale, and reports containing geological, geochemical, and geophysical data compilations. DGGS is conducting a simultaneous surficial-geologic study in the field area largely from interpretation of aerial photography, revision of historical data, and limited field work. From this additional study, we anticipate the completion of a comprehensive-geologic and a surficial-geologic map. DGGS expects to have the maps and data published and available to the public on its Web site (http://wwwdggs.dnr.state.ak.us/) in 2006.

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Dear Readers:

Now that the holiday season is behind us and a new field season approaches, it is a perfect time to review last year's work and outline some plans for the coming season. Our feature article, by one of our field geologists, Jen Athey, is a perfect example of the excellent products coming from our Mineral Resources section and Geologic Communications staff. As you can see, the airborne geophysical/geological mineral inventory program provides a much higher resolution of geologic mapping than can be attained through surface exposures alone, and shows that we are committed to using all the tools necessary to map the geology of Alaska in the greatest detail possible.

This coming season our field work plans include mapping in the Council mining district of western Alaska and the Kavik area of the central Brooks Range mountain front, and we will be initiating surface geologic work along the proposed pipeline corridor from Delta Junction to the Canadian border. This latter project will incorporate the airborne geophysical survey that has just recently been completed, and will focus primarily on geohazards, surficial deposits, and bedrock geology along that route. These are just a few of the exciting projects we have planned and I encourage you to visit the DGGS Web site <http://www.dggs.dnr.state.ak.us> or stop by the office and discuss some of the other programs we have underway.

On the personnel front, I am happy to announce the addition and movement of some important staff. David LePain has taken a job as a Geologist IV in the Energy Resources section and will be leading a new program looking at frontier areas of producing basins, primarily Cook Inlet. David worked for DGGS for a number of years and we are very happy to see him come back to Fairbanks and Alaska geology after a time at the Wisconsin Geological and Natural History Survey. Emily Finzel has taken a Geologist III position in the Energy Resources section and will be in charge of field logistics and mapping for the group.

This year is shaping up to be very exciting and full of great geology.

Thank you for all the support and I hope to see you in the coming year.

Bob Swenson
Acting Director & State Geologist

NEW DGGS PUBLICATIONS

GEOPHYSICAL MAPS & REPORTS

GPR 2006-1. Line, grid, and vector data and plot files for the airborne geophysical survey data of parts of the southern National Petroleum Reserve–Alaska, Northwest Alaska, by Laurel E. Burns, U.S. Bureau of Land Management, Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2006. 3 CD-ROMs. Line data in ASCII format; gridded data in Geosoft and ER Mapper formats; vector files in Autocad version 13 dxf files. Includes 19 maps (aeromagnetic or resitivity) listed below as GPR2006_1_xy as plot files in both HPGL/2 format and postscript printer format, and as Adobe Acrobat format files. For the plotter files, software is needed with ability to plot HPGL2 files for an HP Design Jet 5000/5500 series plotter or postscript files designed for an HP Design Jet 5000/5500 using Postscript 3 printer driver v5.0. The postscript files should plot on all Hewlett Packard plotters that can interpret Postscript 3 files. $30.

GPR 2006-1-1a. Total magnetic field of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains topography. $52.

GPR 2006-1-1b. Total magnetic field of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains magnetic contour lines. $52.

GPR 2006-1-2a. 7200 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains topography. $52.

GPR 2006-1-2b.- 7200 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains resistivity contour lines. $52.

GPR 2006-1-3a. 900 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains topography. $52.

GPR 2006-1-3b. 900 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains resistivity contour lines. $52.

GPR 2006-1-4a. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Misheguk Mountain C-1, C-2, D-1, and D-2 quadrangles, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4b. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass C-5 and D-5 quadrangles, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4c. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass C-4 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4d. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass C-3 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4e. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass C-2 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4f. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass C-1 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4g. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass B-5 and C-5 quadrangles, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4h. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass B-4 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4i. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass B-3 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4j. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass B-2 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-4k. Total magnetic field and detailed electromagnetic anomalies of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, parts of Howard Pass B-1 Quadrangle, 1 sheet, scale 1:31,680. Full color; contains topography and detailed electromagnetic anomalies. $13.

GPR 2006-1-5a. 56,000 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains topography. $52.

GPR 2006-1-5b. 56,000 Hz coplanar resistivity of parts of southern National Petroleum Reserve–Alaska, Northwest Alaska, 4 sheets, scale 1:63,360. Full color; contains resistivity contour lines. $52.

GPR 2006-3. Line, grid, and vector data and plot files for the airborne geophysical survey data of northeast Fairbanks area, Fairbanks and Circle mining districts, Interior Alaska, by Laurel E. Burns, Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2006, 1 CD-ROM. Line data in ASCII format; gridded data in Geosoft and ER Mapper formats; vector files in Autocad version 13 dxf files. Includes 13 maps (aeromagnetic or resitivity) listed below as GPR2006_3_xy as plot files in both HPGL/2 format and postscript printer format, and as Adobe Acrobat format files. For the plotter files, software is needed with ability to plot HPGL2 files for an HP Design Jet 5000/5500 series plotter or postscript files designed for an HP Design Jet 5000/5500 using Postscript 3 printer driver v5.0. The postscript files should plot on all Hewlett Packard plotters that can interpret Postscript 3 files. $10.

GPR 2006-3-1a. Total magnetic field of northeast Fairbanks area, Fairbanks and Circle mining districts, Interior Alaska, 2 sheets, scale 1:63,360. Full color; contains topography. $26.

GPR 2006-3-1b. Total magnetic field of northeast Fairbanks area, Fairbanks and Circle mining districts, Interior Alaska, 2 sheets, scale 1:63,360. Full color; contains magnetic contour lines. $26.

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ALASKA HIGHWAY CORRIDOR GEOLOGY AND GEOPHYSICS

Diana N. Solie[1] and Laurel E. Burns[1]

INTRODUCTION

The Alaska Highway, from the Canadian border to Delta Junction, serves as Alaska's most vital land-based transportation link to the rest of North America. The importance of this highway corridor has been highlighted recently in discussions of the proposed natural gas pipeline, as a possible route from Prudhoe Bay to the Lower 48. An extension of the Alaska Railroad through Canada has also been proposed that would probably follow the Alaska Highway corridor at least in part. In order to make informed decisions regarding alignment and design of these or any other proposed developments, a consistent baseline of publicly available geologic data is required. Having a good understanding of the geology allows us to identify associated geohazards along the corridor, such as areas with the highest potential for active faulting, or where permafrost is present, or areas most likely to experience flooding, liquefaction, or landslides. In addition, geologic mapping along the corridor helps us recognize gravel and other material resources needed for construction projects. For this purpose, DGGS has been funded by the Alaska State Legislature to begin a comprehensive geologic investigation of the proposed gas pipeline corridor from Delta Junction to the Canadian border. Completion of the 200-mile-long project will rely on continued funding through 2010.

The first phase of the Alaska Highway corridor study provided detailed airborne magnetic and electromagnetic geophysical data for a 16-mile-wide swath along the corridor from Delta Junction to the Canadian border. DGGS published the geophysical data in May 2006 and will soon release electrical resistivity profiles and additional gridded data produced from some of the profiles.

The electromagnetic frequencies used for the geophysical survey provide more information for shallower features than those flown in previous DGGS geophysical surveys. This enables us to better interpret the properties of materials within the upper 25 meters, for example to predict aggregate sources or the presence of frozen ground.

Figure 1. *Location map.*

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(continued on page 2)

The second phase of the Alaska Highway corridor study will provide inch-to-the-mile geologic maps of bedrock and surficial geologic units, based on interpretation of geophysical data and aerial photographs, existing geologic maps, and extensive field observations. The first segment of field mapping, begun in 2006 and to be continued in summer 2007, extends from Delta Junction to Dot Lake, encompassing portions of the Big Delta and Mt. Hayes quadrangles in a 12-mile-wide swath. These data are scheduled to be published by June 2008. Based on this mapping, the study will detail the potential for geohazards and materials resources along the corridor. The bedrock information and related geochemical data that come from this project can also be used to evaluate the potential for mineralization.

GEOLOGIC SETTING

The Tanana River, a major tributary of the Yukon River, roughly parallels the Alaska Highway for much of its length. Major tributaries, including the Gerstle, Johnson, Robertson, Tok, Nabesna, and Chisana rivers, flow generally northward out of the Alaska Range and join the Tanana River. The topography south of the Tanana River valley rises abruptly to peaks of the Alaska Range. Within the map area, elevations rise to more than 7,000 feet above sea level, with rugged, glacially-carved ridges and valleys. Treeline is about 3,000 feet in the study area, allowing good bedrock exposure on the higher ridges. In contrast, north of the Tanana River the hills are lower and forested, rising to just over 3,000 feet above sea level. The heavy vegetation that covers much of the map area creates a challenge for field geologists, and suggests that we will need to rely heavily on geophysical data to help extrapolate ground observations in those areas.

The corridor encompasses three physiographic provinces: the Yukon–Tanana Upland north of the Tanana River, the Tanana–Kuskokwim Lowland along the Tanana River valley, and the Alaska Range south of the Tanana River (Holmes and Foster, 1968). Geologically, however, rocks south of the Tanana River have been mapped as subterranes of the Yukon–Tanana terrane (Nokleberg and others, 1992) extending to the Denali fault, rather than as part of the rest of the Alaska Range. The structural relationship of these rocks, lithologically part of the Upland but topographically part of the Alaska Range, to the rocks of the Upland is not clear. Detailed mapping in the proposed map area will provide the opportunity to better understand this major structural break.

The Yukon–Tanana terrane is bounded on the south by the Denali fault, one of the longest strike-slip fault systems in the world (Harp and others, 2003), and on the north by the Tintina fault zone, a major strike-slip system parallel to the Denali fault. The map area occurs about 25 miles north of the Denali Fault and the coinciding southern boundary of the Yukon–Tanana terrane. Both the Denali and Tintina faults have experienced long-term right lateral strike-slip movement. The physical response of the region between these major fault zones has resulted in a complex structural history including extensive left-lateral movement along northeast-trending faults (Page and others, 1995). To date, few of the anticipated faults have been mapped in the map area.

Bedrock to be mapped in 2007 consists mainly of complexly deformed metamorphic rocks that have been intruded by Mesozoic and Tertiary plutonic rocks (Foster and others, 1992). Early mapping in the Mount Hayes Quadrangle assigned the entire metamorphic rock assemblage to the Birch Creek schist unit, regarded as Precambrian (Holmes, 1965; Holmes and Foster, 1968). Later mapping divided the metamorphic rocks in the map area into three subterranes: Lake George subterrane north of the Tanana River, and Jarvis Creek Glacier and Macomb subterranes south of the river (Nokleberg and others, 1992), based on composition and origin of protoliths, present lithology, structure, and metamorphic history (Foster and others, 1994). More detailed mapping should enable us to break out individual geologic units within the plutonic and metamorphic packages.

Surficial geologic deposits in the 2007 map area include materials deposited by glaciers during at least two Quaternary glacial episodes. The younger Donnelly glaciation most likely took place within late Wisconsin time, during the period of 10 to 30 thousand years ago (Reger and Péwé, 2002). The Delta glaciation occurred prior to the Donnelly, and may even encompass more than one event. Detailed mapping of glacial deposits in the corridor provided through this study should help refine our understanding of the glacial history of this part of Alaska.

GEOPHYSICAL SURVEY

The newly acquired aeromagnetic and electromagnetic (EM) data provide information on magnetic susceptibility and electrical conductivity, respectively, of the material in the area. These complementary physical data can provide invaluable clues as to the areal distribution of rock types, breaks in the subsurface due to faults or contacts between rock or soil types, and the distribution of such features as permafrost, the water table, and shear zones. Pre-fieldwork interpretation of the geophysical data will be used to target areas for investigation during the mapping project.

For survey acquisition and processing, DGGS contracted Stevens Exploration Management Company, who used Fugro Airborne Surveys Corporation as a subcontractor. The survey was flown in 2006. Parallel flight lines were aligned slightly west of north, one-quarter mile apart, for the 200-mile-long corridor. The electromagnetic 'bird', containing the electromagnetic transmitters and receivers as well as the magnetometer in this survey, was towed 100 feet above ground level by helicopter.

The magnetometer is a passive instrument that measures the earth's magnetic field in nanoTeslas (nT). Rocks with high magnetic susceptibilities (measured in SI units) locally attenuate or dampen these magnetic signals, producing the relative highs and lows. Iron-rich magnetic minerals such as magnetite, ilmenite, and pyrrhotite have the highest magnetic susceptibility. These minerals commonly occur in mafic volcanic rocks, mafic and ultramafic plutonic rocks, and amphibolites, as well as others. Rocks with low to no iron tend to produce little variation in the magnetic signal. These include silicic volcanic and plutonic rocks, many quartz–mica schists, and most sedimen-

tary rocks. Because the magnetic signal of many rock types overlaps, field checking is needed to make definitive determinations of rock types.

The electromagnetic data provide information about conduction of electromagnetic waves through the sediments and rock types. In general, in the widespread unconsolidated deposits along the Alaska Highway corridor, the finer-grained sediments, such as clays and silts, will be more conductive than peat and sand. Gravel and then bedrock will be markedly less conductive than sand. In bedrock areas, water-saturated clays, graphite, concentrations of some sulfides, and clay alteration of plutonic rocks are generally the most conductive materials. As with the magnetic data, the conductivity of many rock and soil types overlaps and field checking is needed to complete the work.

Each transmitter in the EM system emits primary magnetic fields. When these magnetic fields encounter a conductive unit, an alternating current is formed. This produces a secondary magnetic field, which is read by the appropriate receiver in the bird. The strength of the received signal correlates to the relative electrical conductivity of the materials within the ground below. The different frequencies used for the survey target different depths. Five coplanar (horizontal) electromagnetic coils for this survey ranged between 140,000 and 400 Hz. Because ground penetration correlates inversely with frequency, the 140,000 Hz represents very near surface rocks, but below the active freeze-thaw layer, and the 400 Hz returns signals from deeper rocks. The depth of penetration of an EM signal also depends on the conductivity of the rocks through which the signal is passing; shallower depths are sampled when the material is conductive. The range of frequencies used in this survey yields conductivity (inverse of resistivity) data for a range of depths from about 5 meters as an extreme minimum to a maximum of 150 meters below ground surface.

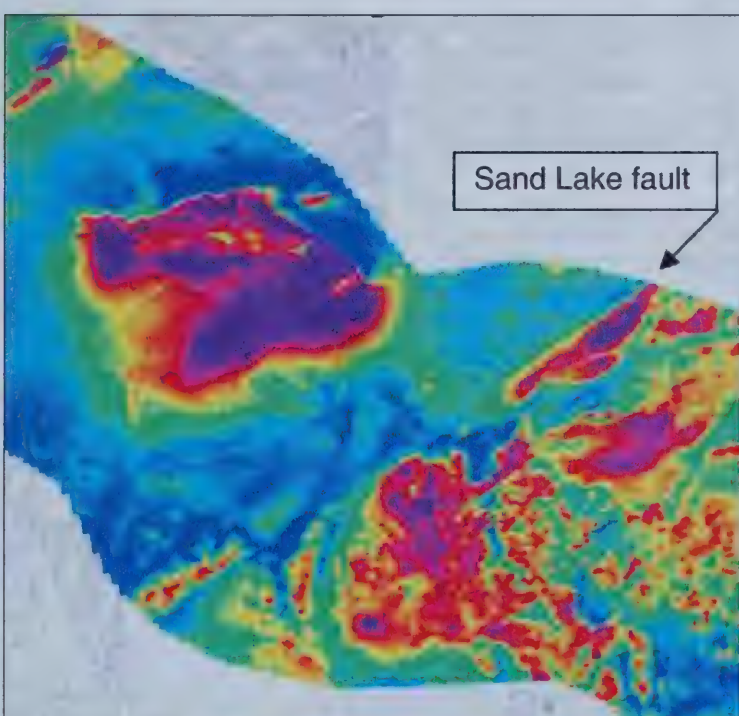

Figure 2. *Airborne total magnetic field survey of a portion of the Mt. Hayes Quadrangle.*

Using several different methods and algorithms, Fugro Airborne Surveys produced resistivity profiles to 100 meters depth for every third flight line for the entire corridor. These profiles are "pseudo-cross-sections" of the resistivity data and yield further information on faulting, trends of deposits, and depths of suspected permafrost, as well as many other items. The profiles are also available for every flight line in three selected areas. For these three areas, grids were also developed that can be used to create three-dimensional visualizations of the resistivity characteristics of the subsurface materials. DGGS will publish the profiles and grids in the first quarter of 2007 (Burns and others, in progress).

GEOHAZARDS

One of the most crucial, but also most difficult, geohazards to assess is the presence of potentially active faults within the corridor. The Alaska Highway corridor is transected by a number of prominent structural features revealed by the geophysical survey, striking northeastward through the map area. One of the most obvious geophysical anomalies crosses the corridor south of Lake George (fig. 2). However, previous mapping has not recognized a contiguous fault across the corridor (Holmes, 1965; Nokleberg and others, 1992). Even so, "this should not be construed as evidence that this region will not be subjected to severe seismic shaking or to faulting of unconsolidated deposits" (Carter and Galloway, 1978). The neotectonic map of Alaska (Plafker and others, 1994) shows faults active in Late Pleistocene and faults suspected of late Tertiary activity in and near the map area.

In light of the high potential for infrastructure development along the Alaska Highway corridor, understanding the structural geology of the map area and whether it presents a potential hazard is critical. By using interpretation of aerial photographs, geophysical data, and careful examination of land formations in the field, this project will identify if there is evidence for recent movement on any observed faults. To gather more detailed information, where feasible we will transect the trace of suspect faults with a shallow trench. This will expose a profile of the sediments to allow observation of features such as offsets in layering or other disruptions, and possibly result in measurements of direction, distance, and timing of motion of the fault.

PRODUCTS

Products released to date include the basic geophysical data in map, grid, and database form, listed below in the first reference cited. Each map included in that publication is also available on the DGGS website (http://www.dggs.dnr.state.ak.us/pubs) in Adobe Acrobat (.pdf) format. An additional geophysical publication will contain the interpretive EM pro-

files and grids as described in this article and several other items. By mid 2008 we will publish 1:63,360-scale bedrock geology maps and surficial geology maps of the segment of the Alaska Highway corridor from Delta Junction to just east of Dot Lake. We will also publish, either as part of those maps or as separate reports, the results of our investigations into geohazards and material resources for that same segment of the corridor. Pending continued funding from the State Legislature, we hope to continue this project to the Canadian border.

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Dear Readers:

Very few geoscientists would dispute the claim that Alaska is a virtual 'candy store' of geology—when compared to other regions of our continent, Alaska certainly has one of the finest 'selections of flavors' to choose from. Besides hosting the largest oil and gas field ever discovered in North America, we are blessed with a multitude of geologic provinces that contain a complex suite of tectonic, sedimentary, metamorphic, mineralized, and magmatic terranes. In addition, the surficial processes that are constantly changing our landscape range from alpine to coastal, and arid-frozen Arctic to coastal rainforest. I cannot think of a geologic discipline that would go wanting for the lack of an exciting problem to decipher, and it could be argued that we have merely scratched the surface.

Your Alaska Division of Geological & Geophysical Surveys is fully engaged in increasing the geologic knowledge of the state and has developed a diverse set of programs to help address myriad geologic issues. New project areas and expansion of existing programs are providing much-needed information that will help explorers, policy makers, and communities make informed decisions in a dynamic world. Recent changes in the global commodity market have catapulted Alaska's vast resource potential into the forefront, and public realization that we live in a complexly interwoven physical and biological environment has fully awakened the debate of human involvement in the earth's natural processes.

These are exciting times.

To address the changing political, economic, and physical environment, the Alaska Geological Survey is in a constant state of metamorphosis. We are expanding our efforts on geohazard analysis across the state to keep pace with increased development activity as well as accelerated natural hazards associated with a warming Arctic. The feature article of this newsletter, by Diana Solie and Laurel Burns, highlights a major project we are undertaking to address geohazards and material sites along the proposed gas pipeline route from Delta Junction to the Canadian Border. This work will dramatically increase our geologic understanding in a poorly mapped area of the state that will likely see a dramatic increase in development activity.

Our energy group has moved into the subsurface with newly acquired data, and broadened its efforts to include a number of poorly understood basins across the state. The minerals group is expanding our airborne geophysical survey coverage and moving our detailed mapping efforts into new areas of mineralization. Our communications group continues to develop our web-served database, which has seen a dramatic increase in data distribution with more than 300,000 maps and reports being downloaded last year alone.

We again encourage you to visit our website (www.dggs.dnr.state.ak.us) or stop by our offices to discuss Alaska's geology and become involved in the cutting-edge work being undertaken at your State Geological Survey. We very much appreciate your input and support.

Sincerely,

Bob Swenson
State Geologist & Acting Director

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IC 56. Using geologic maps, by Athey, J.E., 2007, 2 p. Free.

DGGS NEWSLETTER

NL 2006-2. Alaska GeoSurvey News, by DGGS Staff, 2006, 10 p. Article: A brief overview of Alaska petroleum systems. Free.

RAW DATA FILES

RDF 2006-1. 2006 Bristol Bay, Alaska Peninsula field summary and outcrop sample results from porosity & permeability and mercury injection capillary pressure analyses, by Strauch, A.L., Gillis, R.J., Reifenstuhl, R.R., and Decker, P.L., 2006, 65 p. $7.

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Vol. 9, No. 2, December 2006

A Brief Overview of Alaska Petroleum Systems

Paul Decker

INTRODUCTION

It is no exaggeration to say that energy resource issues are among the defining questions of our time. Debate rages over whether we can depend on oil and gas to fuel our economy over the long term. How will we be able to afford to use fossil fuels as demand increases and supplies dwindle? How long will fossil energy supplies last? How does our ever-increasing consumption impact national security and the global environment?

As pressing as these questions are to all Americans, they are perhaps even more critical to Alaskans. We rely on hydrocarbon fuels not only to survive our long, cold, dark winters, but also as the state's dominant revenue source. Nonetheless, many of us have vague or incorrect conceptions about the formation and distribution of oil and gas in the natural world.

To understand and predict petroleum occurrences, geologists and geophysicists now follow what is known as a "petroleum systems approach," considering and quantifying each of the interdependent processes required for the accumulation of hydrocarbons. This article briefly outlines this analytical approach and highlights key aspects of the petroleum systems at work in Alaska's sedimentary basins (fig. 1).

Figure 1. *Map showing sedimentary basins in Alaska. Multiple petroleum systems are established oil and gas producers in the North Slope province (1) and Cook Inlet basin (2). The Alaska Peninsula (3) and Gulf of Alaska (4) regions are known to possess all of the elements of petroleum systems, but they remain underexplored and commercially unproven. Most of the basins in Interior Alaska (5) are challenged by a variety of issues, though all appear to possess coarse, reservoir-quality sandstones.*

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(continued on page 2)

ELEMENTS OF PETROLEUM SYSTEMS

The basic elements of a functional petroleum system are source rock, reservoir rock, trapping configuration, and seal rock. But it is not enough to simply have each of these components present in a given sedimentary basin—they also have to be in the right places at the right time, and interact in such a way that the whole system can operate properly.

Oil source rocks (usually black shales or limestones) contain elevated levels of organic molecules rich in carbon and hydrogen that, when heated slowly to the right temperature, react to form the mix of chainlike hydrocarbon molecules we call crude oil. The part of a basin that is buried deeply enough to cause this thermal conversion is called "the kitchen." With continued burial and increased heating in the kitchen, these same rocks release less oil and increasing amounts of the lighter, smaller hydrocarbon molecules that make up natural gas. Source rocks that start out rich in carbon but leaner in hydrogen (including coals as well as many shales and limestones) can generate natural gas but not the more hydrogen-rich liquid hydrocarbons. When hydrocarbons are created in the kitchen, their buoyancy quickly drives them to migrate out of the area, following the path of least resistance through the most permeable strata they encounter.

Reservoir rocks are porous and permeable formations that can store oil and gas in the pore spaces between grains (fig. 2) and later allow them to flow out of the rock into wellbores, where they can be extracted. Some of the most efficient petroleum systems have high-quality reservoir formations closely overlying the source rock strata where they act as conduits for hydrocarbons migrating up and out of the kitchen area toward traps closer to the basin edge. Only where these porous, permeable rocks are enclosed in trapping geometries does oil and gas stop migrating and accumulate in the reservoir rock to form fields.

Effective traps consist of reservoir rock layers overlain and/or laterally bounded by impermeable seal rock, and are of two basic types. *Structural traps* occur where the rock layers are deformed by folding or faulting to form large, concave-downward shapes capable of containing buoyant fluids such as oil and gas. *Stratigraphic traps* occur where porous, permeable reservoir rocks are encased in impermeable seal rocks as a result of non-uniform deposition of sediments.

For example, clean sands on a wave-worked beach may grade laterally into a muddy offshore setting, and with time, the muddy offshore zone may migrate over the older beach sand, setting up a possible future stratigraphic trap. Structural traps are usually much easier to identify and generally host the initial oil and gas discoveries in a given basin. Stratigraphic traps are much harder to target, and their successful prediction normally requires more detailed mapping of the subsurface geology. This might be based on either an abundance of previously drilled wells or advanced processing and interpretation of high-quality three-dimensional seismic data. In any case, in order for traps to host oil and gas fields, they must be created prior to hydrocarbon generation, expulsion, and migration from the kitchen. Moreover, they must then remain intact, uncompromised by later folding, faulting, or excessive burial.

NORTH SLOPE PROVINCE

Alaska's North Slope is one of the most prolific petroleum provinces in North America. One reason for this is that the region encompasses effective petroleum systems in each of the three main stratigraphic sequences that developed across the region over the last 350 million years (fig. 3). From oldest to youngest, these first-order geologic packages are called the Ellesmerian, Beaufortian, and Brookian megasequences. In some cases, the three major systems operate independently of one another, with source, reservoir, and sealed traps all occurring in closely related strata. In other cases, the systems overlap, combining elements from two or more stratigraphic sequences.

Overall, the North Slope is sometimes described as 'supercharged' by oil and gas generated in its multiple, high-quality,

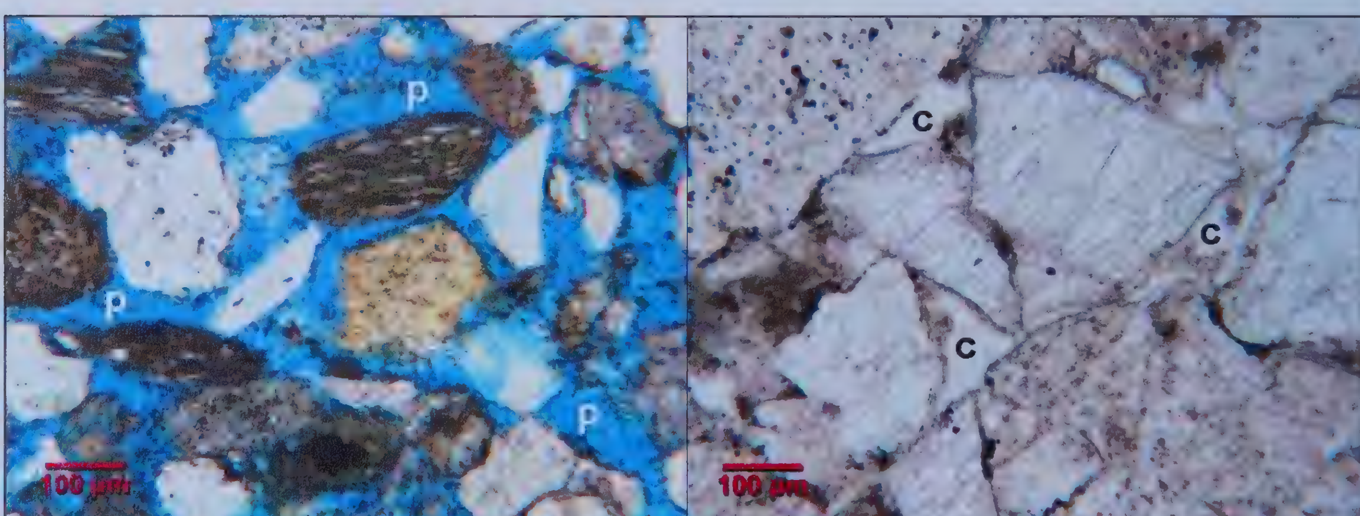


Figure 2. *Microscopic views contrasting reservoir- and non-reservoir-quality sandstones from the Alaska Peninsula–Bristol Bay region. High-quality sandstone at left is from the Tertiary Bear Lake Formation, and has abundant, large, well connected pores (p) capable of storing hydrocarbons and allowing them to flow to producing wells. Non-reservoir sandstone at right from the Jurassic Naknek Formation, with tightly-fitted sand grains and cement-filled pores (c), has essentially no porosity or permeability.*

widespread source rocks in kitchens underlying a large percentage of the region. As a regional generalization, the greatest barrier to oil and gas production on the North Slope is reservoir quality, commonly jeopardized by the presence of too much pore-clogging mud in the system when the strata are deposited. Also, reservoirs that start out as clean sands or limestones often suffer from destruction of the pore system through compactional collapse of relatively weak grains or the chemical precipitation of cements during deep burial by overlying strata.

A brief look at an accumulation produced by each of the North Slope's main petroleum systems provides insights into the characteristic elements, strengths, and risks of each stratigraphic sequence. Remember that many of the North Slope fields would not exist without mixing elements from two or more of these petroleum systems.

Ellesmerian petroleum system. By far Alaska's largest and most widely known oil field, Prudhoe Bay is also the premier product of the Ellesmerian petroleum system, though its oil and gas is a mixture that includes contributions from younger sources. Current estimates of ultimate recovery from the main Prudhoe Bay field are 13.77 billion barrels of oil, plus natural gas liquids and 27.3 trillion cubic feet of natural gas. Of this total, more than 80 percent of the oil has already been produced, while about 85 percent of the gas remains in the ground. The Triassic Ivishak Formation is the major reservoir, consisting of fluvial and deltaic sandstones and conglomerates. Most of the oil and gas was sourced from shaly limestones of the Triassic Shublik Formation, though portions came from the Jurassic Kingak Formation (lower part of the Beaufortian sequence) and from the lower Cretaceous HRZ shale (base of the Brookian sequence). The Prudhoe trap is an enormous container created in two stages during early Cretaceous time: (1) rift margin faulting that uplifted the Barrow Arch, and (2) the erosion and shale deposition that followed; as such it is a hybrid structural/unconformity trap. Despite numerous faults that cut the reservoir, the trap is securely sealed by two thick shale units, the Jurassic Kingak Formation and the Cretaceous Pebble Shale.

Although the Ellesmerian sequence includes spectacular reservoir quality at Prudhoe Bay and several other nearby fields, geologic conditions were less favorable for depositing and preserving high-quality reservoirs over many parts of the North Slope, making reservoir formation the riskiest element of the Ellesmerian petroleum system in a regional sense. The Ellesmerian's greatest asset is the source component; Shublik and older oil- and/or gas-prone source rocks are believed to be present and thermally mature for hydrocarbon generation across most of the North Slope.

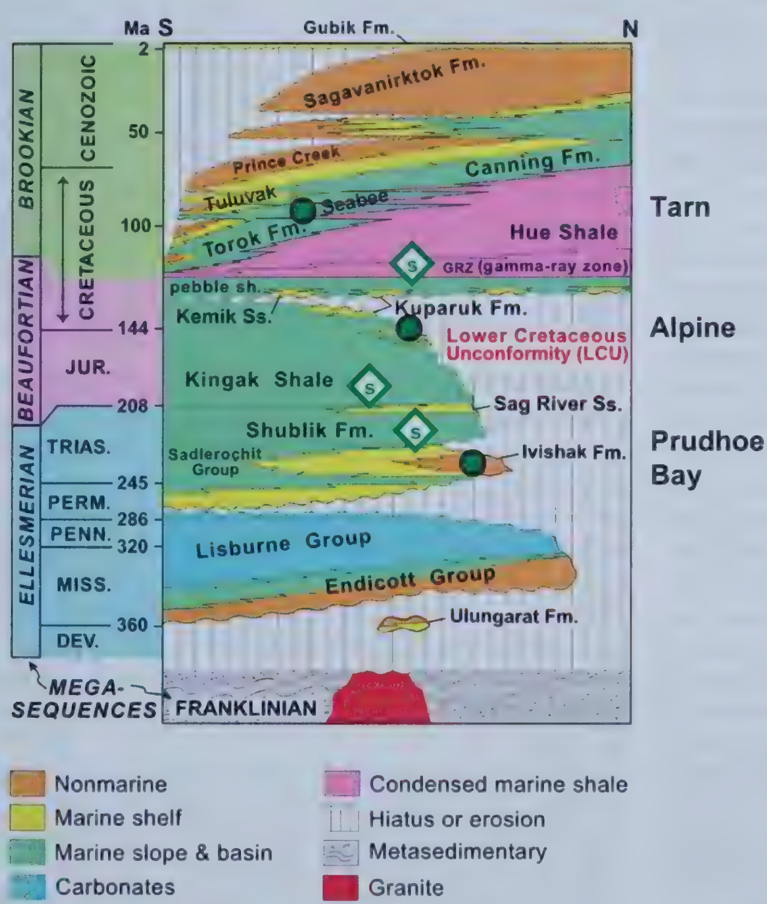


Figure 3. *Chronostratigraphic chart for the North Slope petroleum province showing the major stratigraphic sequences, geologic time scale, stratigraphic column, and the oil and gas fields (dots) and source rocks (diamonds) discussed in text. Note that GRZ (gamma-ray zone) is synonymous with HRZ (highly radioactive zone), and describes the gamma-ray well log response of this Lower Cretaceous shale. Modified from Garrity and others (2005).*

Beaufortian petroleum system. The surprise 1994 discovery of oil-saturated sandstone of latest Jurassic age in the Colville River Delta opened a new exploration play in northern Alaska and established the presence of a self-contained petroleum system in the Beaufortian sequence. This is the suite of strata deposited during the initial rifting phases that led to the opening of the Beaufort Sea. The Alpine sandstone, reservoir unit for the oil field of the same name, is the only confirmed Beaufortian rock of latest Jurassic age. This unit is anomalous compared to the rest of the Kingak Formation, which is dominated by older shales and poor quality sandstones. It now appears likely that Alpine-aged sandstones were deposited in the shallow water rimming much of the uplifted Barrow Arch rift shoulder, but were eroded away across large portions of its original extent before deposition of lowermost Cretaceous shales. However, prior to the Alpine discovery, rocks from the latest Jurassic time interval were not known to be present at all, much less to be shorezone sandstones with fair to good reservoir quality.

Just as intriguing was the recognition that the Alpine's oil is stratigraphically trapped. The reservoir sandstone is encased in sealing mudstones, and can in many cases only be imaged using relatively recent advances in 3D seismic processing. Subsequent drilling indicates the trap is tightly sealed and much larger than originally estimated, containing an oil column at least 600 feet thick comprising estimated ultimate recoverable reserves of 465 million barrels with no overlying gas cap and no underlying water-saturated zone.

Yet another unforeseen aspect of the Alpine discovery is the quality and source of its oil. Its density and viscosity, as well as its asphaltene and sulfur content are all much lower than oils from Prudhoe Bay and Kuparuk fields. These favorable attributes make the oil more valuable and more efficiently recovered and are now known to be characteristic of oil sourced from the pure shales of the lower Jurassic part of the Kingak Formation. Somehow, despite the Kingak's shaly makeup, the source rocks of the lower part are directly linked with a migration route to the reservoir sandstones in the upper part.

Although the Beaufortian sequence also includes the Kuparuk Formation and the related Point Thomson sandstone, most of its reservoir-quality sandstones are of only local extent. Elsewhere, equivalent strata typically lack porosity and permeability because they are either too fine grained, too rich in clay matrix, or damaged by cementation, making reservoir quality the greatest overall exploration challenge. On the other hand, trap and seal are normally a safe bet in the Beaufortian sequence, a consequence of the high proportion of shales relative to coarser-grained rocks.

Brookian petroleum systems. The Brookian sequence is the youngest major package of sedimentary rocks in northern Alaska. These sediments were derived by erosion of the Brooks Range, and filled in the Colville Basin north of the range, eventually spilling over the old Beaufortian rift shoulder and into the Beaufort Sea. The Brookian hosts oil and gas accumulations spanning a broad range of trap types and reservoir sandstones. So-called "topset" sandstones were laid down in nearshore shallow marine or onshore nonmarine environments, whereas "turbidite" reservoirs were deposited from turbidity currents in deep water at or near the base of the continental slope.

The Tarn Field is a good example of the Brookian petroleum system supplying all the components independently of the other systems. Its reservoir is a turbidite known as the Bermuda sandstone of the mid-Cretaceous Seabee Formation. Like most turbidites, the Bermuda interval comprises reservoir-quality sandstones across only a fraction of its full extent. Fortunately, the porosity and permeability thresholds for a viable reservoir are extended at Tarn by the presence of very light oil, similar to the Alpine oil, but sourced from the lower Cretaceous HRZ shale that blankets much of the bottom of the Brookian basin. All told, Tarn is now expected to ultimately yield 120 million barrels of oil and 34 billion cubic feet of gas. Because the better turbidite sandstones pinch out laterally into siltstones and shales, Brookian turbidite reservoirs are commonly stratigraphically trapped. The fairway for the turbidite exploration play is thus much broader than for topset plays, which require either structural traps or special circumstances to form stratigraphic traps.

Strengths and risks of the Brookian petroleum system vary greatly by play. The critical risk in exploring for Brookian turbidites is that the sandstone may lack sufficient porosity and permeability—being either too fine-grained, too muddy, or too compacted and cemented due to deep burial—to host a reservoir. The stratigraphic traps encasing the turbidite reservoirs are the play's greatest strength. Prospecting for Brookian topsets is completely different. Since the topset sands are widespread and have not been as deeply buried as their deepwater counterparts, reservoir presence and effectiveness is normally the greatest strength. Regionally, the greatest risk associated with the topset play is oil quality. The shallow depth of many keeps them cool enough that hydrocarbon-metabolizing bacteria can thrive and biodegrade the oil, making it viscous, more expensive to recover, and less valuable.

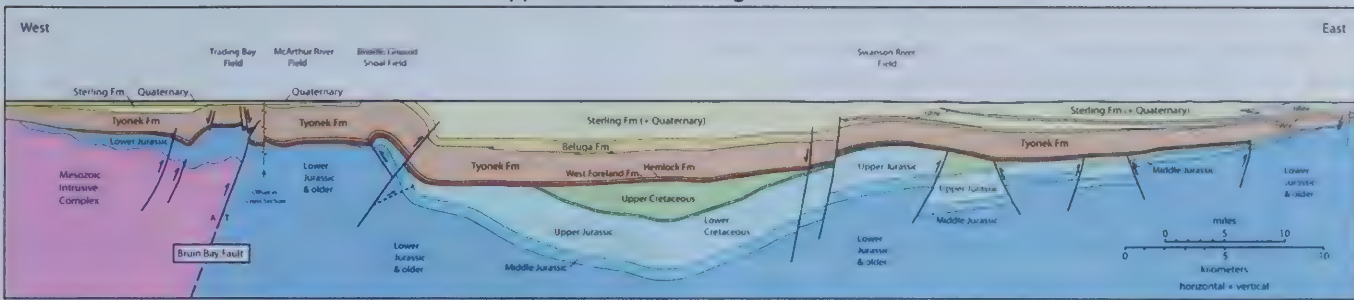
COOK INLET BASIN

For a number of years prior to the discovery of vast oil resources at Prudhoe Bay, southern Alaska's Cook Inlet basin was a hotbed of exploration, resulting in numerous commercial oil and gas discoveries that were quickly brought online. This phase of active drilling rapidly proved up what are now recognized as two independent hydrocarbon systems, while a more speculative third system has remained an elusive target. The established systems are both contained in Tertiary-aged reservoirs, but have entirely different source and migration histories (fig. 4). The unproven system would depend on the older Mesozoic rocks maintaining adequate reservoir quality, which appears to occur very rarely in this basin.

Tertiary-reservoired oil system. All the oil fields in Cook Inlet have one thing in common: Their production comes from reservoir formations in the lower part of the nonmarine Tertiary succession. Tertiary strata blanket a regional angular unconformity that beveled off the more deformed Mesozoic succession below. Along the eastern and western edges of the basin, Tertiary reservoirs consist largely of gravelly alluvial fans and sandy braided channels shed from the adjacent upland areas. Toward the basin axis, south-flowing river channels migrated side to side across their floodplains, depositing sandy fluvial reservoirs interlayered with overbank silts, clays, and coals.

Carbon isotopes and biological marker compounds found in Cook Inlet oils trace them back to the Jurassic Tuxedni Group and/or Triassic Kamishak Formation, oil-prone marine source rocks in the Mesozoic succession below the angular unconformity in the deep, central part of the basin. The oil migrated up out of this central kitchen, across the unconformity, up the flanks of the basin into nearby anticlinal traps, and probably into a number of yet-to-be-discovered stratigraphic traps. Some of these oil fields produce modest amounts of associated gas dissolved in the oil, but the fields do not have free gas caps.

Upper Cook Inlet Geologic Cross Section



Modified from Haeussler and others (2000), revised from Boss and others (1976)

Figure 4. *Geologic cross section through Upper Cook Inlet, modified from Haeussler and others (2000), revised from and Boss and others (1976). Oil sourced from the Middle Jurassic Tuxedni Group migrated across the angular unconformity into lower Tertiary reservoirs of the West Foreland, Hemlock, and Tyonek formations. Biogenic gas sourced by bacterial degradation of coals forms commercial accumulations in the upper Tertiary sandstones of the Tyonek, Beluga, and Sterling formations.*

Tertiary-reservoired gas system. Cook Inlet's gas reserves occur in some of the same Tertiary formations as the oil, but are produced mainly from the upper formations in which no oil has been discovered. Unlike the oil, which was generated from thermal maturation of the Mesozoic sources, almost all of the basin's dry methane gas was generated as a by-product of bacteria feeding on the Tertiary coals in the subsurface. Initially, this biogenic gas dissolved in the water, saturating the coals. Late-stage folding and anticlinal uplift throughout the basin, together with the even more recent disappearance of thick glaciers, caused a drop in the pore pressure, which allowed the dissolved methane to bubble out of solution as a free gas phase. Only then could the biogenic gas begin to migrate out of the coals and accumulate in nearby sandstone reservoirs. The northern edge of the Cook Inlet basin has seen recent coalbed methane exploration, targeting gas still contained in the microporous structure of the coals themselves. Up to this point, coalbed methane projects have been thwarted by subsurface structural complexity. Extensive faulting and folding have broken and jostled the coal seams into small, tilted compartments that are difficult to drain efficiently.

Mesozoic-reservoired oil and gas system. For decades, companies have hoped to find Mesozoic sandstones that have maintained sufficient porosity and permeability to serve as reservoirs. To this point, there has been only minor encouragement on this front; in nearly all cases, the older sandstones are too tightly cemented to serve as conventional reservoirs. However, there is ongoing interest in exploring for Mesozoic-sourced oil and gas that never migrated very far beyond the kitchen. Locally, conventional sandstone reservoirs might have escaped destruction if their pores were filled with oil early enough to shut down chemical cementation. Alternatively, the source rocks themselves may serve as unconventional reservoirs, as is the case in some other sedimentary basins. Both scenarios carry substantially more exploration risk, and any current contribution to production from beneath the Base Tertiary unconformity is minor at best. For now, an independent Mesozoic petroleum system remains unproven.

NONPRODUCING BASINS – STRENGTHS AND RISKS

Several regions of the state host sedimentary basins that have no current commercial oil or gas production. As outlined below, many of the critical petroleum system elements are present, but the lack of economic success to date makes it unclear whether these elements are interacting as needed to make up functional petroleum systems.

Alaska Peninsula. The long peninsula separating the Cook Inlet and Bristol Bay basins was first explored in the early 1900s with wells drilled on the southeast side near active oil and gas seeps. Exploration shifted to the northwest side of the Alaska Peninsula in the late 1950s through early 1980s before being halted by concerns over fisheries protection. Regular leasing was renewed in 2005 with the establishment of the Alaska Peninsula areawide sale, encompassing nearly 5 million gross acres. This area is dramatically underexplored, especially by modern methods. All the necessary components appear to exist for both Tertiary and Mesozoic petroleum systems, but it remains to be seen whether they are properly integrated to result in major hydrocarbon accumulations that can be economically developed in this remote region.

Oil- and gas-prone source rocks are clearly present and functioning in areas with prolific oil and gas seeps, but their subsurface distribution and maturity is uncertain in other areas. The region has a complex thermal and tectonic history due to the evolution of a plate boundary dominated by oblique subduction of the Pacific plate, creating further uncertainties regarding reservoir quality, thermal maturity, and the location and integrity of both structural and stratigraphic traps. Recent industry interest focuses on natural gas as more likely than oil, and recognizes that much of the gas potential is offshore beneath the federal waters of Bristol Bay.

Gulf of Alaska. As on the Alaska Peninsula, the Gulf of Alaska saw early exploration activity driven by prolific oil seeps. The Katalla area enjoyed a brief era of minor oil production from shallow wells in the early 1900s, but more recent drilling has

turned up no oil or gas accumulations that would be commercial today. Again, the key elements of petroleum systems are shown to exist, with excellent Tertiary source rocks and reservoirs, and a plate-boundary tectonic setting favorable for creating structural and stratigraphic traps. Nonetheless, the modern explorationist faces a serious challenge connecting all the different elements in definable prospects of commercial size. Much of the Gulf of Alaska region suffers from low thermal maturity, elusive stratigraphic traps, or extreme deformation and destruction of reservoir quality.

Interior Basins. A number of unproven sedimentary basins developed in Interior Alaska during Tertiary time, including the Yukon Flats, Nenana, Minchumina, Holitna, Copper River, and Susitna basins. Most are thought to have developed either as subsiding pull-apart basins related to large strike-slip displacements on the Denali–Farewell, Tintina–Kaltag, Iditarod, and Border Ranges–Castle Mountain fault systems. In general, Alaska's Interior basins contain relatively thick sandy or gravelly intervals that would serve as oil and gas reservoirs. They are challenged either by lack of traditional oil- and gas-prone source rocks, low thermal maturity, structural complexity, questionable seal integrity, or some combination of these issues. Coals are developed in many of the basins, and might source biogenic gas, as is the case in Cook Inlet, but the Interior basins lack the significant late-stage uplift-related depressurization required to break the gas out of solution to allow migration and accumulation.

CONCLUSIONS

Alaska is an enormous state comprising a number of very different geologic provinces (fig. 5). Not surprisingly, the oil and gas productivity of its sedimentary basins is equally variable. The petroleum systems approach used by oil and gas explorers provides a simple but powerful tool for gaining insight into why some of Alaska's basins are world-class producers, whereas others have yet to produce any commercial hydrocarbons. This discussion has focused mainly on the geologic realities of Alaska's petroleum systems—perhaps mere accidents of nature and geologic time—that determine how much oil and gas are created and reservoired in a basin. Without a doubt, dozens of other factors are also at play in determining whether and when a basin's oil and gas resources become commercially developed. Transportation infrastructure, proximity to local and export markets, global supply and demand, and the balance between resource development and environmental protection are just a few items on what could be a very long list. But aren't these really cultural and societal issues that might change with time? There is perhaps one thing we can count on—the future can't change Alaska's geologic past.

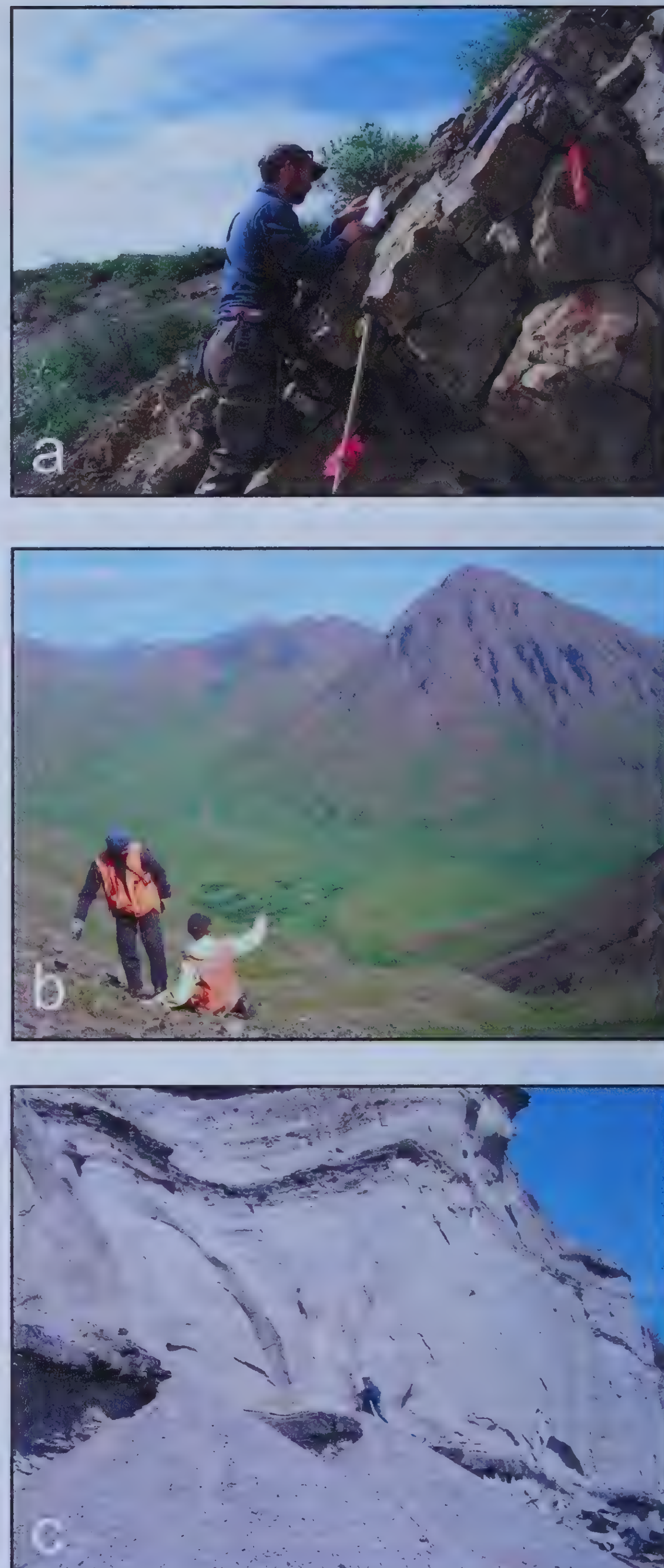


Figure 5. *Recent DGGS-led geologic field programs on the North Slope (a), Alaska Peninsula (b), and in the Cook Inlet basin (c) remain a cornerstone of petroleum systems studies in Alaska. Projects include collaboration with geologists and geophysicists of the Alaska Division of Oil & Gas, U.S. Geological Survey, University of Alaska, and other universities, and are increasingly focused on integrating outcrop data with subsurface well and seismic data.*

NEW DGGS PUBLICATIONS

GEOPHYSICAL MAPS & REPORTS

GPR 2006-6. Line, grid, and vector data, and plot files for the airborne geophysical survey of the Alaska Highway corridor, east-central Alaska, by Burns, L.E., Fugro Airborne Surveys, and Stevens Exploration Management Corp., 2006, 1 disk. DVD format. Line data in ASCII format; gridded data in Geosoft and ER Mapper formats; vector files in AutoCAD version 13 dxf files. Includes maps listed below as GPR 2006-6-xy as plot files in both HPGL/2 format and as Adobe Acrobat format files. The HPGL2 files will only plot with software that has ability to plot HPGL2 files produced for an HP Design Jet 5000/5500 series plotter. $10.

GPR 2006-6-1A. Total magnetic field of the Alaska Highway corridor, east-central Alaska, parts of Big Delta and Mt. Hayes quadrangles, by Burns, L.E., Fugro Airborne Surveys, and Stevens Exploration Management Corp., 2006, 1 sheet, scale 1:63,360. Full color; contains topography. $13.

GPR 2006-6-1B. Total magnetic field of the Alaska Highway corridor, east-central Alaska, parts of Mt. Hayes Quadrangle, by Burns, L.E., Fugro Airborne Surveys, and Stevens Exploration Management Corp., 2006, 1 sheet, scale 1:63,360. Full color; contains topography. $13.

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Dear Readers:

One can count on many things in Alaska: Termination dust in the fall, dark winters, dog teams howling at feeding time, mosquitoes in the field, and—one of my favorites—continual and dynamic change. DGGS starts this new year with a number of changes including new personnel, new administration, old volcanoes erupting anew, and high commodity prices that are spurring exploration activity across the state. The challenge of change is what keeps the staff at DGGS pushing hard to keep up with the demand for data and expertise on geologic hazards, oil and gas potential, and mineral resources across the state. We are meeting these challenges.

This issue's feature article, by Paul Decker of the Division of Oil & Gas, is an excellent example of how your survey is retooling its approach to geologic investigation. On the energy front, we have embarked on a number of new projects that will incorporate all the publicly available subsurface data to apply a systems approach to understanding the geologic history of an area. Diane Shellenbaum, who was recently hired by the Division of Oil & Gas, is helping us build a database of seismic reflection data that will dramatically increase our interpretation capabilities. We have completed our first year in the field on the Cook Inlet project and are already documenting some important finds relating to the basin-edge geometry of that complex system. The future for this group is very exciting.

The engineering geology section is continuing their work on many collaborative projects in volcanic hazards, tsunami-inundation mapping, and gas pipeline corridor mapping to address hazards, material sites, and bedrock geology. The group is also nearly finished with development of a cooperative teaching program, MapTEACH, which is taking modern geologic mapping techniques to the rural classroom and showing the students how understanding the natural environment is key to a sustainable future. Please visit our website to see some of these exciting programs.

Our minerals section has had a very busy year and is putting the final touches on inch-to-the-mile mapping on the Seward Peninsula. New data coming out of these mapping efforts are providing a much more detailed look at the complex metamorphic history of the area, which will dramatically improve our understanding of the mineralization and regional tectonics. The geophysics acquired through our mineral inventory program has proven to be crucial to providing this level of mapping and geologic knowledge. Our annual minerals report attests that the industry is seeing an unprecedented amount of activity and providing both revenue and jobs across the state.

Our publications section is working on getting all the new data and reports available to the public through our website and also expanding our digital database to include legacy data, the GMC geologic collection, and the many new maps and reports that are the keystone of our work.

We at DGGS hope you have a safe and festive holiday season and look forward to hearing from you in the coming year.

Sincerely

Bob Swenson
Acting Director & State Geologist

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THE ALASKA VOLCANO OBSERVATORY - 20 YEARS OF VOLCANO RESEARCH, MONITORING, AND ERUPTION RESPONSE

Since 1988, the Alaska Volcano Observatory (AVO) has been monitoring volcanic activity across the state, conducting scientific research on volcanic processes, producing volcano-hazard assessments, and informing both the public and emergency managers of volcanic unrest. Below are some examples of the activity at Alaska's volcanoes that have held the attention of AVO staff.

(a) 1989-90, Redoubt (b) 1992, Bogoslof (c) 1992, Spurr (d) 1992, Westdahl (e) 1993, Seguam

(f) 1994, Kanaga (g) 1996, Akutan (h) 1996, Pavlof (i) 1997, Okmok (j) 1998, Korovin

(k) 1999, Shishaldin (l) 2004-06, Spurr (m) 2005, Veniaminof (n) 2005, Chiginagak

(o) 2006, Augustine (p) 2006, Cleveland (q) 2006, Fourpeaked (r) 2007, Pavlof

Photo credits: (a) J. Warren, (b) T. Keith, USGS, (c) R. McGimsey, USGS, (d) C. Dau, USFWS, (e) U.S. Coast Guard (1977 photo), (f) E. Klett, USFWS, (g) R. McGimsey, USGS, (h) S. Schulmeister, (i) J. Freymueller, UAF/GI, (2002 photo), (j) R. McGimsey, USGS, (k) C. Nye, ADGGS, (l) D. Schneider, USGS, (m) K. Wallace, USGS, (n) J. Schaefer, ADGGS, (o) C. Read, USGS, (p) NASA, (q) K. Lawson, (r) C. Waythomas, USGS.

To see more photographs of Alaska volcanoes and learn more about these eruptions and others, visit the Alaska Volcano Observatory website at www.avo.alaska.edu.

Monitoring the Active Volcanoes of Alaska

BY Janet Schaefer and Chris Nye

Introduction

Active volcanoes in Alaska? Yes! In fact, there are more than 50 historically active volcanoes in Alaska. Hardly a year goes by without a major eruption from a volcano in the Aleutian Arc.

Alaska's volcanoes are potentially hazardous to passenger and freight aircraft as jet engines sometimes stall after ingesting volcanic ash. On December 15, 1989, a Boeing 747 flying 240 kilometers (150 miles) northeast of Anchorage encountered an ash cloud erupted from Redoubt Volcano and lost power in all four jet engines. The plane, with 231 passengers aboard, lost more than 3,000 meters (~9,800 feet) of elevation before the flight crew was able to restart the engines (Casadevall, 1994). After landing, it was determined the airplane had suffered about $80 million in damage (Brantley, 1990).

We estimate that more than 80,000 large aircraft per year, and 30,000 people per day, are in the skies over and potentially downwind of Aleutian volcanoes, mostly on the heavily traveled great-circle routes between Europe, North America, and Asia. Volcanic eruptions from Cook Inlet volcanoes (Spurr, Redoubt, Iliamna, and Augustine) can have severe impacts, as these volcanoes are nearest to Anchorage, Alaska's largest population center.

The series of 1989–1990 eruptions from Mt. Redoubt were the second most costly in the history of the United States, and had significant impact on the aviation and oil industries, as well as the people of the Kenai Peninsula.

The three eruptions of Mt. Spurr's Crater Peak in 1992 deposited ash on Anchorage and surrounding communities, closed airports, made ground transportation difficult, and disrupted air traffic as far east as Cleveland, Ohio.

The 1912 Katmai eruption, which formed the Valley of Ten Thousand Smokes on the Alaska Peninsula, was the largest 20th-century eruption on earth.

Some quick facts and figures about the volcanoes in Alaska:

- Alaska contains in excess of 100 volcanoes and volcanic fields that have been active within the last 2 million years.
- More than 50 of these have been active in historic time (about the last 200 years).
- These volcanoes make up about 80% of all active volcanoes in the United States and 8% of all active above-water volcanoes on earth.

Most of Alaska's volcanoes are located along the 2,500-kilometer-long (1,550-mile-long) Aleutian Arc, which extends westward to Kamchatka and forms the northern portion of the Pacific "ring of fire" (fig. 1, Monitoring status of active volcanoes in Alaska, pgs. 6-7). Other volcanoes that have been active in the last few thousand years exist in southeastern Alaska and in the Wrangell Mountains. Smaller volcanoes, some active within the last 10,000 years, are found in interior Alaska and in western Alaska as far north as the Seward Peninsula. Information on all of these volcanic centers can be found on the AVO website, www.avo.alaska.edu.

The Alaska Volcano Observatory

The volcanology section at the Alaska Division of Geological & Geophysical Surveys (DGGS) works within the larger context of the Alaska Volcano Observatory (AVO), a joint program of the United States Geological Survey (USGS), the Geophysical Institute of the University of Alaska Fairbanks (UAF-GI), and DGGS. AVO was formed in 1988, and uses federal, state, and university resources to monitor and study Alaska's hazardous volcanoes, to predict and record eruptive activity, and to mitigate volcanic hazards to life and property. AVO has responded to more than 18 episodes of volcanic eruption or unrest since its inception.

AVO has three primary objectives:

- To conduct monitoring and other scientific investigations in order to assess the nature, timing, and likelihood of volcanic activity;
- To assess volcanic hazards associated with anticipated activity, including types of events, their effects, and areas at risk; and
- To provide timely and accurate information on volcanic hazards, and warnings of impending dangerous activity, to local, state, and federal officials and the public.

The three component agencies of AVO each bring particular strengths to the observatory, and at the same time share general expertise in volcanology (fig. 2). Among the agencies, DGGS has the clearest mandate for baseline geologic mapping and hazard studies. DGGS also has a remarkable degree of flexibility, which has allowed us to build and serve a large database of descriptive material about volcanoes and to build a cutting-edge system for intra-observatory communication and data sharing, providing notices of eruptions and unrest to users in public, private, and government sectors. Among volcano observatories worldwide, AVO has become the leader in information dissemination using powerful database and web-based tools. Particular strengths of the USGS are the federal hazards mandate and direct ties to federal agencies. UAF-GI brings a research mandate and access to resources (such as satellite data downlink centers) otherwise beyond the financial capability of AVO.

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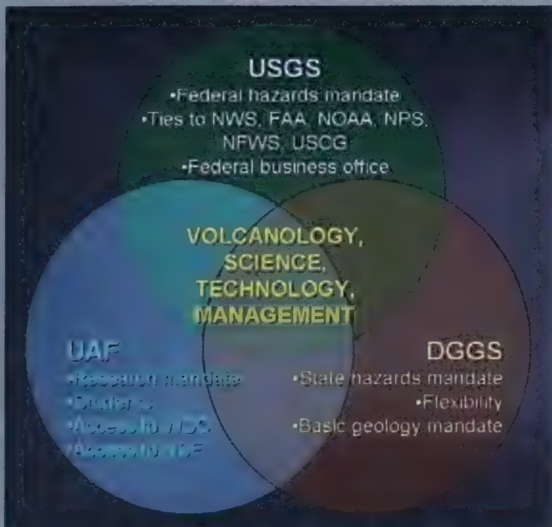
THE ALASKA VOLCANO OBSERVATORY



The Alaska Volcano Observatory is an interagency program composed of DGGS, the U.S. Geological Survey, and the University of Alaska Fairbanks Geophysical Institute. The component agencies bring distinct mandates and strengths to the Observatory, yet share a common grounding in volcanology.

Figure 2. *The three-agency organization of the Alaska Volcano Observatory.*

Recent volcanic unrest provides AVO volcanologists with scientific opportunity and challenges

Over the last three years (2005–2007), nine Alaska volcanoes were at an elevated level-of-concern color code (fig. 3): Martin, Spurr, Tanaga, Cleveland, Fourpeaked, Korovin, Veniaminof, Pavlof, and Augustine. Activity at these volcanoes ranged from phreatic explosions (Fourpeaked) and small ash emissions (Veniaminof) to lava flows and fire fountaining (Pavlof) to large ash clouds affecting air traffic (Cleveland and Augustine). The three events summarized below (the 2006 eruption of Augustine volcano, the 2006 eruption of Fourpeaked volcano, and the 2005 acid crater lake drainage at Chiginagak volcano) offer glimpses into the variety and complexity of work that the DGGS volcanology section geologists are involved in. The scientific data collected during these episodes of volcanic unrest continues to occupy scientists' time as they work to understand the volcanic processes that took place before, during, and after these events.

The 2006 eruption of Augustine Volcano

On January 11, 2006, Augustine volcano entered an explosive phase of eruption, sending ash to more than 9 kilometers (29,500 feet) above sea level (Power and others, 2006). The initial explosive phase was followed by lava effusion that continued through late March. In addition to the large ash clouds, the eruption generated pyroclastic flows, and a new lava dome whose steep sides occasionally failed, generating block and ash flows down the volcano's flanks. AVO staff stepped up to the task and were able to detect changes in earthquake activity and ground deformation that led to the raising of the color

Volcano Alert Levels

Normal
Volcano is in typical background, noneruptive state or, *after a change from a higher level*, volcanic activity has ceased and volcano has returned to noneruptive background state.

Advisory
Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level*, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.

Watch
Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway but poses limited hazards.

Warning
Hazardous eruption is imminent, underway, or suspected.

Aviation Color Codes

GREEN
Volcano is in typical background, noneruptive state or, *after a change from a higher level*, volcanic activity has ceased and volcano has returned to noneruptive background state.

YELLOW
Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level*, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.

ORANGE
Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].

RED
Eruption is imminent with significant emission of volcanic ash into the atmosphere likely **OR** eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

Figure 3. *Ground hazard Alert Level and aviation Color Codes (Gardner and Guffanti, 2006).*

code from GREEN (volcano is dormant; normal seismicity and fumarolic activity) to YELLOW (volcano is restless; eruption may occur) on November 29, 2005, almost 2 months prior to the eruption.

Prior to the unrest detected in November 2005, the monitoring instrumentation at the volcano consisted of seven short period seismometers, one broadband seismometer, and six continuous GPS stations. As unrest continued, AVO began adding more monitoring instrumentation; by the end of the eruption, Augustine was the most well-monitored volcano in Alaska with five short-period seismometers, one strong motion seismometer, three temporary broadband seismometers, three EarthScope permanent continuous GPS stations, five temporary continuous GPS stations, three webcams, two time-lapse cameras, two radiometers, and one pressure sensor (figs. 4 and 5). The information received from these instruments allowed AVO to monitor significant changes at the volcano and to produce timely and accurate information releases regarding hazards at the volcano. In addition, the data acquired by these instruments and subsequent site visits have provided AVO volcanologists with a wealth of information for the study of active volcanic processes such as precursory seismicity and ground deformation, pyroclastic and lava flow dynamics, lahars, dome growth, and ash and aerosol dispersion in the atmosphere.

Figure 5. *Webcam on Augustine Island. Images from the Augustine Island webcam were viewed more than 8 million times during January 2006. The camera also documented a spectacular pyroclastic flow on January 29, 2006. Photo by M. Coombs, January 12, 2006.*

Figure 4. *Radiometer at Burr Point on Augustine Island. AVO geologists use the radiometer and forward-looking infrared (FLIR) camera to measure temperatures of the summit dome, lava flows, and pyroclastic flows. Photo by T. Plucinski, March 15, 2006.*

AVO's response to the 2006 eruption of Augustine volcano serves as a flagship example of how current technological advances in instrumentation, data acquisition, and web-based communication, combined with a staff of experienced, knowledgeable volcanologists, can work together to provide both the public and emergency managers with accurate and timely information during hazardous volcanic events.

A volcano awakens—the 2006 eruption of Fourpeaked volcano

On September 17, 2006, Fourpeaked volcano, located at the northeastern end of the Alaska Peninsula, produced a plume of steam, ash, and SO_2 (+CO_2) gas that rose to 6,000 meters (20,000 feet) above sea level (fig. 6). The plume was observed by eyewitnesses and recorded by weather radar and SO_2-sensitive satellite imagery. Air and ground reconnaissance by DGGS and USGS geologists revealed a linear series of vents in the summit glacier, stretching about 1 kilometer (0.6 mile) down the north flank of the volcano. The melting snow and ice produced a debris flow of hydrothermally altered volcanic rocks, clay, and sulfur, mixed with ice and boulders up to 5 meters (16 feet) in diameter.

The explosions at Fourpeaked volcano, a volcano with no known previous activity in the last 10,000 years, reminds us that volcanoes operate on a geologic time scale and that hazardous conditions can exist at volcanoes that have shown no activity in historic time. AVO continues to monitor activity at Fourpeaked with a webcam, intermittent gas flights, and a seismic network.

The 2005 catastrophic acid crater lake drainage, lahar, and acidic aerosol formation at Mount Chiginagak volcano

Mount Chiginagak is a hydrothermally active volcano on the Alaska Peninsula, approximately 170 kilometers (100 miles) south–southwest of King Salmon. Sometime between November 2004 and May 2005, a 400-meter-wide (~1,300-foot-wide), 100-meter-deep (~300-foot-deep) crater lake developed in the formerly snow- and-ice-filled crater of the volcano (fig. 7). In early May 2005, an estimated 3 million cubic meters (106 million cubic feet) of sulfurous, clay-rich debris and acidic water exited the crater through tunnels in the base of a glacier that breaches the south crater rim (Schaefer and others, 2006). More than 27 kilometers (17 miles) downstream, the acidic waters of the flood reached approximately 1.3 meters (~4 feet) above current water levels and inundated an important salmon spawning drainage. The flow acidified Mother Goose Lake from surface to depth (pH of 2.90 to 3.06) and prevented the annual salmon run in the King Salmon River. A release of caustic gas and acidic aerosols from the crater accompanied the flood, causing widespread vegetation damage along the flow path.

Figure 6. *The September 17, 2006, eruption of Fourpeaked volcano as viewed from Homer, Alaska. Image courtesy of Lanny Simpson, Alaska High Mountain Images.*

A DGGS-led interdisciplinary science team has been monitoring the status of the remaining crater-lake water that continues to flow into Mother Goose Lake. As of August 2007, the persistently high acidic conditions of Mother Goose Lake once again prevented the spawning run of salmon to this drainage. As part of a volcano-hazard assessment, the science team, in cooperation with Northern Arizona University lake core specialists, cored the bottom sediments of Mother Goose Lake with the goal of determining the recurrence interval for this type of acid flood from Chiginagak. Although Chiginagak volcano is not seismically instrumented, AVO monitors activity at the volcano with satellite imagery and with images sent to us from local pilots and residents in the area.

AVO's database-driven website allows for efficient communication of volcano information

DGGS takes a lead role in providing timely and accurate information about volcanic unrest to both the public and emergency management officials. The DGGS-run AVO website (www.avo.alaska.edu) and its back-end database, GeoDIVA (Geological Database of Information on the Volcanoes of Alaska) is a world-class example of efficient information management related to volcanic activity. Highlights of both the internal and public websites, as well as GeoDIVA, are described below.

AVO's internal website:

The internal website has become the central location for managing information releases, images, field projects, and volcano observations. The database-driven applications AVO has developed for its internal site allow AVO personnel to use a web-based interface to efficiently distribute Volcanic Activity Notifications (VANs) to communicate changes in volcanic activity to government agencies, who then use the information to make decisions about governmental response to eruptions. This information is also simultaneously posted on AVO's public website, making it immediately available to the general public. The AVO internal website also displays complex near-real-time seismological and satellite data over the web for observatory staff, making distributed monitoring possible, instead of monitoring only from within the lab.

AVO's public website:

The public website provides both the general public and emergency managers with up-to-date information on volcanic activity, as well as background information on the volcanoes of Alaska including scientific literature, maps, eruption histories, and images. The AVO public website (www.avo.alaska.edu)

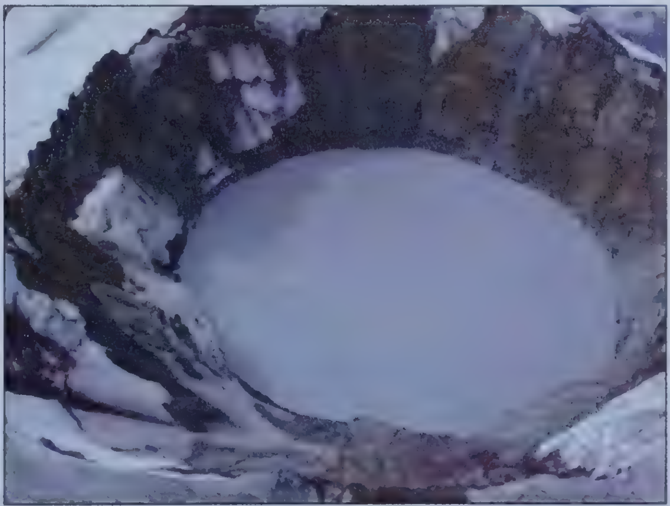
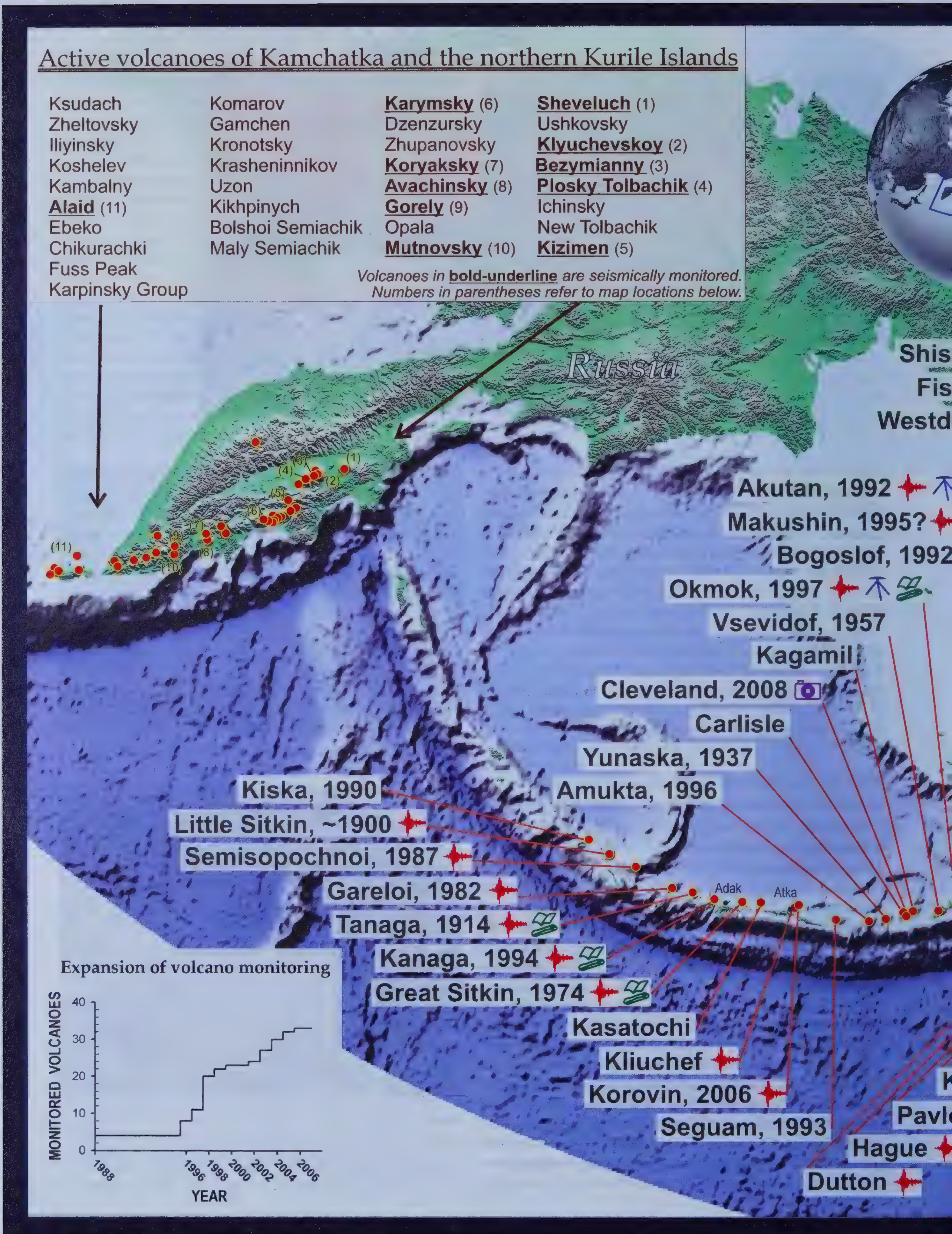


Figure 7. *The crater lake at Chiginagak volcano. In 2005 this crater lake partially drained, sending a flood of acidic water into Mother Goose Lake and the King Salmon River. Photo by R. McGimsey, August 21, 2006.*


Active volcanoes of Kamchatka and the northern Kurile Islands
Ksudach
Zheltovsky
Iliyinsky
Koshelev
Kambalny
Alaid (11)
Ebeko
Chikurachki
Fuss Peak
Karpinsky Group
Komarov
Gamchen
Kronotsky
Krasheninnikov
Uzon
Kikhpinych
Bolshoi Semiachik
Maly Semiachik
Karymsky (6)
Dzenzursky
Zhupanovsky
Koryaksky (7)
Avachinsky (8)
Gorely (9)
Opala
Mutnovsky (10)
Sheveluch (1)
Ushkovsky
Klyuchevskoy (2)
Bezymianny (3)
Plosky Tolbachik (4)
Ichinsky
New Tolbachik
Kizimen (5)
Volcanoes in bold-underline are seismically monitored.
Numbers in parentheses refer to map locations below.
Russia
Shis
Fis
Westd
Akutan, 1992
Makushin, 1995?
Bogoslof, 1992
Okmok, 1997
Vsevidof, 1957
Kagamil
Cleveland, 2008
Carlisle
Yunaska, 1937
Amukta, 1996
Kiska, 1990
Little Sitkin, ~1900
Semisopochnoi, 1987
Gareloi, 1982
Tanaga, 1914
Kanaga, 1994
Great Sitkin, 1974
Kasatochi
Kliuchef
Korovin, 2006
Seguam, 1993
Adak
Atka
Pavl
Hague
Dutton
Expansion of volcano monitoring
MONITORED VOLCANOES
YEAR
0
10
20
30
40
1988
1996
1998
2000
2002
2004
2006

Monitoring status of active volcanoes in Alaska
EXPLANATION
2008 year of most recent eruption
seismic network
continuous deformation network (GPS)
telemetered remote camera (webcam)
updated geologic map and/or reports
51 active volcanoes are shown. There are about 90 additional geologically young volcanoes.
All volcanoes are monitored several times each day using AVHRR and other satellites.
AREA
Barrow
Kotzebue
Nome
Fairbanks
Bethel
Anchorage
Valdez
Kenai
Seward
Homer
Juneau
Dillingham
Naknek
King Salmon
Kodiak
Ketchikan
Chignik
Cold Bay
Sand Point
King Cove
Unalaska
Alaska
Canada
Amak
ldin, 2004
r, 1826
l, 1992
Gilbert
Wrangell , 1902
Drum - Klawasi
Spurr, 1992
Redoubt, 1990
Iliamna
Augustine, 2006
Douglas
Fourpeaked, 2006
Kukak
Ugashik-Peulik
Ukinrek Maars, 1977
Chiginagak
Aniakchak, 1931
Veniaminof, 2008
oreanof
2007
KATMAI GROUP
Snowy
Katmai, 1912
Griggs
Trident, 1974
Novarupta, 1912
Mageik
Martin

serves about 1,500,000 pages and approximately 300 gigabytes of data to well over 100,000 unique visitors per month. It is among the top ten USGS and USGS-affiliated websites in the country. DGGS was the original creator of the AVO website more than a decade ago, and continues to manage the site.

GeoDIVA: Geologic Database of Information on Volcanoes in Alaska

Tying it all together is GeoDIVA. GeoDIVA is the back-end database driving both the internal and public websites. The mission of GeoDIVA is to maintain complete, flexible, timely, and accurate geologic and geographic information on Pleistocene and younger Alaska volcanoes (those that have erupted in approximately the past 2 million years) for scientific investigation, crisis response, and public information in a dynamic, digital format. This information system is the most comprehensive, accurate, and up-to-date source of information on Alaska volcanoes available anywhere, online or in printed form. GeoDIVA is being developed in modules, which are released when finished, to streamline the delivery of information to the public (fig. 8). GeoDIVA uses the AVO website as its primary means of information dissemination.

Module	Status	Notes
Bibliography	Complete through 2006	Will be updated yearly to include new publications; fully searchable.
Basic volcano information	Complete	137 major and 197 minor volcanic features in Alaska: 54 historically active volcanoes (using newly refined definition)
Eruption history information	Complete through mid 2007	Information, actual text, and references for more than 400 historic eruptions.
Images	Structure complete—data loading in progress	Currently contains more than 11,000 pictures, figures, and maps. Images from previous years, as well as current photographs are being added.
Sample information	Structure complete—data loading in progress	Currently contains information for ~3,000 samples. Published sample information, as well as newly-collected samples, are being added.
Geochemistry	Structure complete—data loading in progress	Geochemistry data loaded for more than 1,200 samples (~45,000 records). Currently adding analyses from published sources.
Petrology	Structure complete—data generation and loading in progress	Planned arc-wide thin section images and descriptions. ~50 Augustine thin sections with 1,000 point counts complete.
Hand sample storage	Structure complete	Sample cataloging in progress. Fairbanks storage 80% complete.
FieldDIVA	Beta phase	Mini-GeoDIVA for field use. (No field work done in summer 2007.)
GIS data	Needs analysis complete, hardware/software tools selected	Currently constructing database tables to hold metadata and testing hardware/software tools.
Geochronology	Planned for FY08	Arc-wide age dates and references, including radiocarbon dates.

Figure 8. *GeoDIVA module status.*

AVO implements new volcano hazard notifications for volcanic activity

As part of the National Volcano Early Warning System (NVEWS) initiative, the national volcano-monitoring community has been working to standardize official information-release formats. Two new update formats have resulted: VAN (Volcano Activity Notification), and VONA (Volcano Observatory Notice for Aviation). The intent of this change is to provide a clearer and more consistent statement of volcano hazard information. It is our hope that the more structured format of VAN and VONA will enable users to more quickly find the hazard content of most interest.

AVO is the test case for these formats, and DGGS has created the database structure and web application to create these information statements. As the other U.S. volcano observatories adopt this standard for releasing information, DGGS will serve as the primary contact for installing the application and database subsystem, as well as for future upgrades to the system.

A summary of AVO information products is listed below:

VAN: Volcano Activity Notice
Important announcement of volcanic activity or significant change in activity, aviation color code, or alert level.

VONA: Volcano Observatory Notice for Aviation
Rigorously formatted message focusing on ash cloud hazards.

DAILY STATUS REPORT:
Short statement on the status of volcanoes at elevated aviation color code or alert level.

WEEKLY SUMMARY:

A recap of activity over the past week and current status of monitored volcanoes.

INFORMATION STATEMENT:

Expanded background information, hazard scenarios, announcements of new monitoring benchmarks, etc.

In addition to these information products, AVO staff make frequent calls directly to the Federal Aviation Administration, the National Weather Service, local U.S. military bases and airports, the Governor's Office of the State of Alaska, the Alaska Department of Emergency Services, airports and air carriers, and municipal and other civil authorities in the areas around the volcano.

Looking to the future

As AVO celebrates its 20-year anniversary this year, we are looking back on two decades of growth: growth in both instrumentation and data streams and growth in our knowledge of Alaska's volcanoes. We are now in a better position technologically to efficiently communicate volcano hazards to the public and emergency managers, and in a better position scientifically to better understand eruption processes and to predict eruptive behavior.

As more seismic, geochemical, geodetic, volcanic gas, and age data is collected and our understanding of Aleutian Arc magmatism grows, there will be a push for a more arc-wide synthesis of information. Answers to larger-scale questions, such as the following, can be attempted:

- What are the trends in magmatic production throughout the history of the arc?
- What do geochemical trends tell us about deep magma injection and mantle processes?
- Is there a pattern in seismic, gas release, and geodetic data that can help us predict volcanic eruptions?

The DGGS volcanology section staff look forward to pursuing answers to these questions with our continued participation in the Alaska Volcano Observatory. We will continue to excel in providing comprehensive information on Alaska volcanoes through our management of GeoDIVA and the AVO website. Our commitment to our objectives remains clear: we will represent the State of Alaska's interests and help mitigate risks to public safety and health by providing information on volcanic hazards as they affect human activity.

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Dear Readers:

Hello again, and thanks for picking up our newsletter and getting up to speed on the latest news at DGGS. As always, we are up to our Brunton compasses in map compilations, spreadsheets of analyses from last summer's samples, and logistical plans for the coming field season. I encourage you to visit our website and download our latest annual report (http://www.dggs.dnr.state.ak.us/webpubs/dggs/ar/text/ar2007.PDF) for summaries of all the projects our staff are diligently working on.

I also want to thank Janet Schaefer, geologist with the Volcanology Section, for providing the excellent article on the volcanoes in Alaska and the activities of the Alaska Volcano Observatory. That program, operated in partnership with the U.S. Geological Survey and the University of Alaska Fairbanks, is one of the flagship programs here at the State Survey and we are very proud to be an active member. The federal support that has made this program a reality has provided an incredible service to the public, the aviation sector, and many other industries operating in the Cook Inlet and Alaska Peninsula region. Additionally, this group has helped to significantly advance the science of volcanology at a local and international scale.

One "geologic" issue that is worth discussing since it will likely be affecting us all in the coming years is Global Climate Change. Who could have envisioned that such relatively benign words (to a geologist, that is) would strike such fear in the hearts of so many people? Those of us who are intrigued by the physical history of the earth have spent our careers studying the rock record and deciphering the results of dramatic variation in both climate and sea

level through geologic time. As was pointed out so aptly by Kirk Johnson, Director of the Denver Museum of Natural History, "Hippos in London and alligators in Stavanger are not really anomalies, but more the norm when one considers the whole picture of earth's history." In fact, climate observations being made today are not necessarily surprising to a geologist thinking in terms of geologic time.

Nevertheless, a vast majority of the public do not concern themselves with geologic time, nor with the fact that the polar regions have been ice-free much longer during earth's history that they have had ice caps. The voting public is much more interested in recent trends in temperature and how this will all play out within their lifetime. More importantly, the general public is fearful ("Be Very Worried," TIME magazine, April 2006) of how the currently forecasted change, and attempted mitigation of that change, will affect their lifestyles, financial investments, and the lives of their children. Those are important things to worry about!

Policy makers at both the federal and state levels are busy working up bills aimed at reducing our greenhouse gas emissions and encouraging a switch of energy sources to those that emit less (or no) CO2. Unfortunately this is not a simple situation that can easily be dealt with by hasty legislation.

Take a look at a few interesting points to ponder:

- There are more than 6 billion humans currently alive on the planet, with a projected 9 billion people to be alive at some point during our children's lifetimes (by 2050).
- Human expansion and activity has had a dramatic effect on surficial and atmospheric processes on earth, and will continue to do so with increasing intensity.
- The amount of increased energy production that will be needed to sustain a 30 percent increase in population in the next 45 years (assuming the current distribution of lifestyles) is commensurate with the energy development that has occurred over the last 150 years.
- There were 1.5 billion people on earth, and huge herds of wild buffalo roaming the central U.S. grasslands a mere 150 years ago.
- The development and production of sustainable energy sources at the scales needed to sustain current lifestyles is difficult to comprehend without significant changes in technology.
- All production of energy involves some form of action/reaction, and if produced in large quantities, will result in some form of environmental degradation.
- The United States has a little more than 4 percent of global population yet consumes 25 percent of the world's energy production and has, until recently, enjoyed cheap and abundant energy that has fueled and sustained a robust U.S. economy.
- CO2 emissions from human activity, as well as natural emissions, are clearly contributing to global temperature rise, but are not the whole story.
- Global temperatures have changed dramatically without anthropogenic influx of CO2.
- If all countries would have ratified the Kyoto Protocol, and were able to meet the reduction timetables, the ultimate predicted 2100 global temperature would be offset by 5 years, to 2105.
- The United Nations predicts that sea level will rise about 1 foot by 2100.
- Global sea level has risen about 1 foot since 1860.
- Glaciers have been continually receding since the Little Ice Age in the late 1800s.
- Rates of glacial retreat have accelerated in recent decades.
- Global average temperature has risen by about 1.4°C since 1900. The IPPC models predict that it will take another 50 years to see the same rise.
- Temperatures will not fluctuate equally across the globe.
- There have been major floods and erosive events happening every year, all over the globe, during all global climate scenarios.
- Flooding and erosion are disasters only when we build infrastructure or allow development in hazard-prone areas (i.e., floodplains are called floodplains for a reason).
- The northern 'tree-line' has been moving north since the last ice age, and likewise has moved both north and south dramatically over time.

The bottom line: There are no easy answers to the questions being raised. Unfortunately, suggestions of alternate hypotheses for any of the polarized viewpoints are often met with vigorous denial and debate, and at times even name-calling. I believe it is critical that we all try to understand what the facts are, realize that dramatic environmental change has been ubiquitous throughout earth's history, think critically about what should be considered solvable problems and define the root of those problems, think long-term into both the future and the past, and attempt to

work together on finding realistic solutions or responses to the impacts human activities are having on the planet we call home. Finally, we must never forget the resilience and unpredictability of life, nor that of the planet earth.

Bob Swenson
Alaska State Geologist

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THE TRANSITION FROM TRADITIONAL TO DIGITAL MAPPING: MAINTAINING DATA QUALITY WHILE INCREASING GEOLOGIC MAPPING EFFICIENCY IN ALASKA

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INTRODUCTION

The Alaska Division of Geological & Geophysical Surveys (DGGS) Mineral Resources section collects, analyzes, and publishes geological and geophysical information on Alaska's State- and Native-owned lands in order to inventory and manage Alaska's mineral resources. Knowledge of Alaska's mineral resources and framework geology is key to developing and managing a strong mineral industry in the state, which in turn provides employment for Alaska's citizens and revenue to local governments. The Mineral Resources section typically maps and publishes at least one geologic map per year in an area of high mineral potential. In an effort to further streamline the methodology of producing these maps, the DGGS Mineral Resources section is investigating the potential of digital field mapping to create maps more efficiently. Other DGGS sections that conduct fieldwork and publish maps (Energy Resources, Volcanology, and Engineering Geology) may also adopt this technology as situations allow. DGGS anticipates that the move to digital mapping will take a number of years to fully implement and may involve a few false starts. Here, we discuss the issues encountered so far and the choices made to further our objective—increased efficiency via digital mapping.

WHAT IS DIGITAL MAPPING?

Digital mapping is defined as using a computer or personal digital assistant (PDA) to show and record information that has traditionally been recorded on paper, whether on note cards, in a notebook, or on a map. Geologic mapping is an interpretive process involving multiple types of information, from analytical data to personal observation, all synthesized and recorded by one person. With field experience over time, geologists generally develop efficient, effective personal styles of mapping with which they are comfortable. This "traditional" geologic mapping can be accomplished by a geologist almost as well in inclement weather and when surrounded by mosquitoes as in ideal conditions.

Computer technology and software are now becoming portable and powerful enough to take on some of the burden of the more mundane tasks a geologist must perform in the field, such as precisely locating oneself, displaying multiple maps, plotting structural data, and color coding different physical characteristics of a rock, stratigraphic units, or contact types. Additionally, computers can now perform some tasks that were difficult to accomplish in the field, for example, recording text or voice digitally and annotating photographs on the spot. For digital mapping to become the standard operating procedure, geologists must use the computer in the field to become more efficient, retain their effectiveness as scientists, and create a new but comfortable, personal mapping style.

WHY ARE WE CONSIDERING DIGITAL MAPPING?

DGGS is constantly looking for ways to improve its geologic mapping workflow. In the end, given the normal, interrelated parameters of funding, available personnel, and time, we want to be as efficient as possible to produce the best possible product. We believe that digital mapping may get us closer to our goal. The main factor driving this effort is the 'time' parameter, in a number of ways.

As of 2006, geologic mapping had been completed for only about 16 percent of Alaska's 586,000-square-mile area at a scale larger than 1:250,000 (fig. 1). Due in part to the scale of available U.S. Geological Survey topographic maps as well as the coverage of existing geologic mapping, most new mapping in the lower 48 states is published at a scale on the order of 1:24,000, while new mapping in Alaska is generally published at scales of 1:50,000 or 1:63,360. At the current rate of mapping, DGGS estimates that it will take 250 years to cover the remaining State- and Native-owned bedrock areas of Alaska with 1:63,360-scale geologic maps. That daunting amount of work requires us to focus on areas with time-sensitive, high-impact value to the state, such as mineral and energy potential, hazards to citizens and infrastructure, and transportation corridors.

Not only is there a lot of ground to cover, but a very short season in which to perform fieldwork. The optimal weather window in Alaska lasts three months: June, July, and August.

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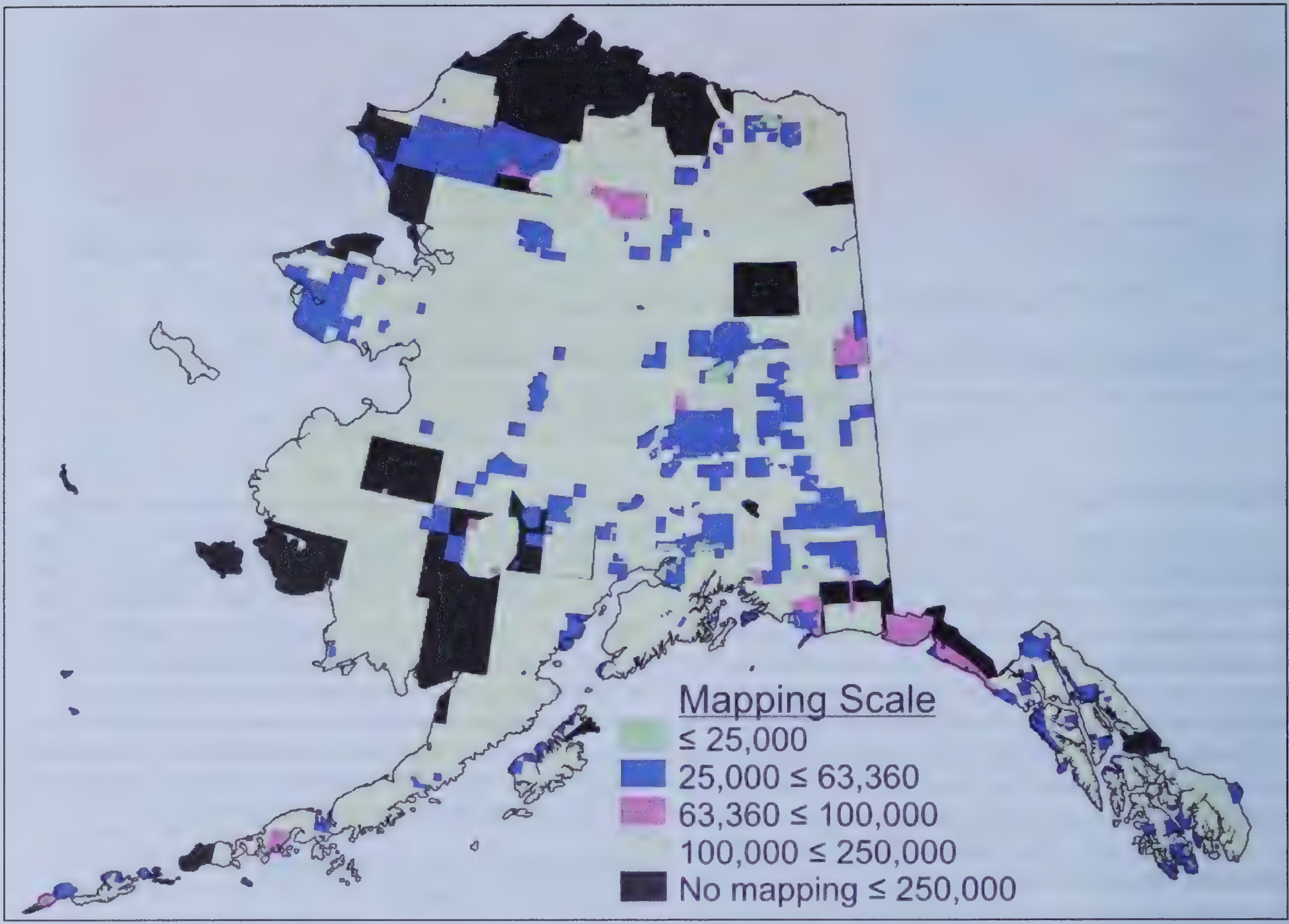

Figure 1. Map of Alaska showing status of bedrock geologic mapping at various scales as of 2006. Note: A significant portion of the Aleutian Islands are not shown on this figure.

Cold temperatures, snow cover, ice overflow in streams, and frozen ground severely hamper geologic fieldwork at other times of the year. The ever-rising cost of fieldwork also plays a large role in the amount of ground covered in a year. Since most of Alaska is inaccessible by road, helicopter transport is a necessary but expensive tool for fieldwork. Other large field expenses include helicopter fuel, fuel transport and storage, remote lodging, food and gear transportation, personnel travel, and rock-sample shipments. To take advantage of the short field season and minimize field costs, DGGS typically deploys a group of five or six geologists that work in the field for up to two months at a time.

Timely release of data to the public and prompt fulfillment of obligations to funding sources are also very important. For example, the Federal STATEMAP program, one of our major funding sources for geologic fieldwork, has a turn-around time of one year for submitting products. With the current mapping methodology, DGGS is challenged to meet this deadline. We believe that the greatest benefit of digital mapping will be a decrease in the amount of project time necessary for data entry, potentially decreasing the overall time needed to complete a project.

EFFECTS ON THE GEOLOGIC MAPPING PROCESS

DGGS Mineral Resources section first started looking at digital mapping in 2005 as a way to streamline the mapping process. Throughout the mapping process, digital mapping has positive and negative effects; only an assessment of its impact on the project as a whole will show whether it helps or hinders. For simplicity, the mapping process is divided into field operations, data entry and basic data management, and data analysis. The current traditional methodology and the advantages and disadvantages of digital mapping are discussed below for each category. Particularly important advantages or disadvantages are *italicized*.

Effects on Fieldwork

Currently, DGGS Mineral Resources section employs the team model to conduct fieldwork. A crew of five or six geologists works in the same general area and compares observations nightly. Geologic observations are recorded on rain-proof standardized note cards (fig. 2) and plasticized paper maps. GPS locations are recorded on paper and saved in the GPS. Observations are compiled by each crew member onto a single mylar

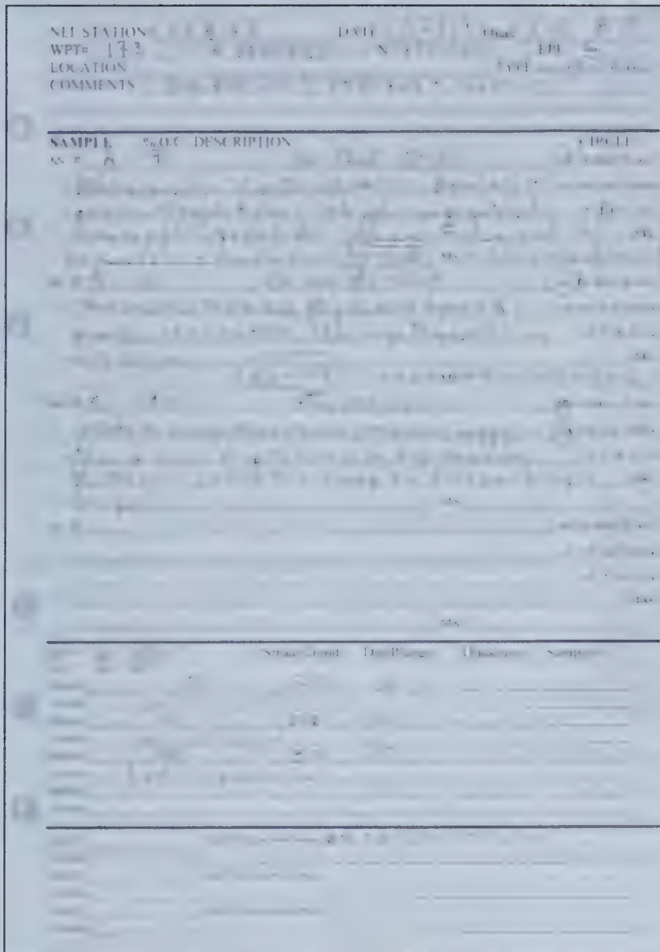

Figure 2. Example of a completed field note card.

basemap in the field office. No one geologist is responsible for the interpretation of an area; instead, geologic interpretations are stronger because the whole crew provides input. Project managers are responsible for arbitrating final interpretations. With the use of digital computers in the field, the recording of observations will change dramatically.

<u>Advantages of Digital Field Mapping: Field Operations</u>

- Computer screen automatically shows the geographic location of the geologist from the GPS.
- Feature data and attributes are entered directly into GIS. Features can be automatically color coded.
- Station (point) attribute data such as location, rock type, stratigraphic unit, textures, mineralogy, and magnetic susceptibility are recorded directly by the geologist into a database. The geologist has total control of how the data are parsed into the database.
- Structural data are plotted automatically.
- Geologists can pare down lengthy narrative descriptions into multiple data fields, making the data more easily searchable and queryable.
- *Feature (point, line, and polygon) attributes are saved as digital text.*
- Geologists can upload each others' data files for the next day's fieldwork as reference.
- Multiple maps and imagery (geophysics, orthophotos, etc.) are easily carried and displayed on-screen.
- Geologists can take photographs and annotate them in the field. Photographs are immediately associated with a location.
- Hand-drawn sections, stratigraphic columns, outcrop interpretations, and other drawings are captured digitally. Drawings are immediately associated with a location.

<u>Disadvantages of Digital Field Mapping: Field Operations</u>

- Computers and related items (extra batteries, rain-proof cases, etc.) have to be carried in the field.
- Because computers are more fragile than waterproof paper, geologists have to take more care with them. (In most cases, short of a complete computer submersion in water, data can be recovered from the hard drive.)
- Geologists must undergo extra training to use the hardware, software, and database and be comfortable with their use.
- *Data entry into the computer by the geologist takes longer than physically writing on paper, possibly resulting in longer field programs.*
- Descriptive narratives often convey to the reader detailed information through imagery that is not communicated by the same data in parsed format.
- Geologists may be inclined to shorten narratives because they are more difficult to enter, resulting in loss of data.
- Details present in some hand-drawn figures like stratigraphic sections, columns, and outcrop interpretations cannot be captured by tablet-stylus entry, resulting in loss of data.
- Geologists may have a more difficult time seeing the regional perspective on a seven-inch computer screen than on larger paper maps, because panning is required.

Effects on Data Entry and Basic Data Management

DGGS Mineral Resources section currently hires student interns to perform data entry and basic data management for field projects. In the field office, the intern enters GPS data and field station data from standardized note cards into an Access database (fig. 3). The intern translates poor handwriting and abbreviations, interprets the geologic notes, and parses the data into a complicated set of database forms. It is not uncommon for data to be mistranslated or parsed into incorrect fields within the database, and these errors are difficult to identify.

In the past few years, interns have spent up to seven months during and after the field season performing data entry. This part of our current methodology needs the most improvement, since interpretation by the geologist must wait until data loading is completed. A long period of data entry can delay the whole project.

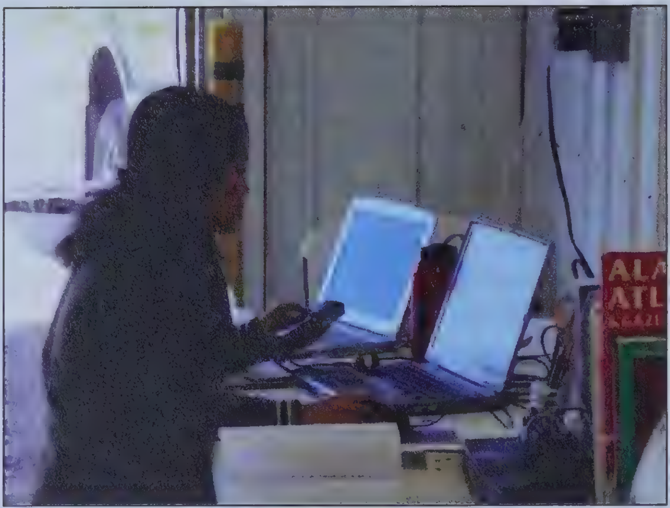

Figure 3. Student intern Liping Jing downloads GPS data into the database.

Advantages of Digital Field Mapping: Data Entry and Management

- *Data entry by geologists only (no student intern) takes less total time, potentially reducing the overall time needed to complete a project.*
- Data entered by geologists have fewer errors.
- Interns have additional time during the day to work with field geologists.
- Post fieldwork, interns' time is better spent gaining experience and helping with sample preparation, data analysis, and GIS.

Disadvantages of Digital Field Mapping: Data Entry and Management

- Interns need additional training in database replication and synchronization.
- Nightly, databases need to be downloaded, synchronized, and uploaded onto field computers.
- Interns need training in GIS and operation of field computers.
- Nightly, GIS files need to be backed up from field computers, compiled, and re-uploaded.
- There are no original, hardcopy field maps or notes to archive. Paper is arguably a more stable medium than digital format.

Effects on Data Analysis

Geologic units in Alaska are typically defined at the scale of 1:250,000. The more detailed 1:63,360-scale mapping completed by DGGS tends to break out new lithologies (rock units with specific physical characteristics) and change previous geologic interpretations. Defining new lithologies and creating a bedrock geologic map is an iterative process requiring the spatial analysis of field data, airborne magnetics and resistivity geophysical data, geochemistry, petrography (classification of rocks by microscopic examination), age data, and other information. Mineralogical and textural data and magnetic susceptibility are queried from the database to help differentiate lithologic units (fig. 4). Digital mapping would affect when data analysis could occur, but not greatly affect the process itself.

Advantages of Digital Field Mapping: Data Analysis

- *Analysis of field data can start immediately after returning from the field, since the database has already been populated.*
- GIS data input in the field can be directly added to the digital working copy of the map.

Disadvantage of Digital Field Mapping: Data Analysis

- Data entered by multiple geologists contain more inconsistencies than data entered by one person, making the database more difficult to query.

DIGITAL FIELD MAPPING EQUIPMENT

In practice, digital geologic mappers are expensive and difficult to outfit. The initial cost of computing and supporting equipment may be significant. In addition, equipment and software must be replaced occasionally due to damage, loss, and obsolescence. Hardware and software only recently (in 2007 and 2008) became available that can satisfy most of the criteria DGGS identified in 2005 as necessary for digital mapping (table 1). Products moving through the market are quickly discontinued as technology and consumer interests evolve. A product that works well for digital mapping may not be avail-

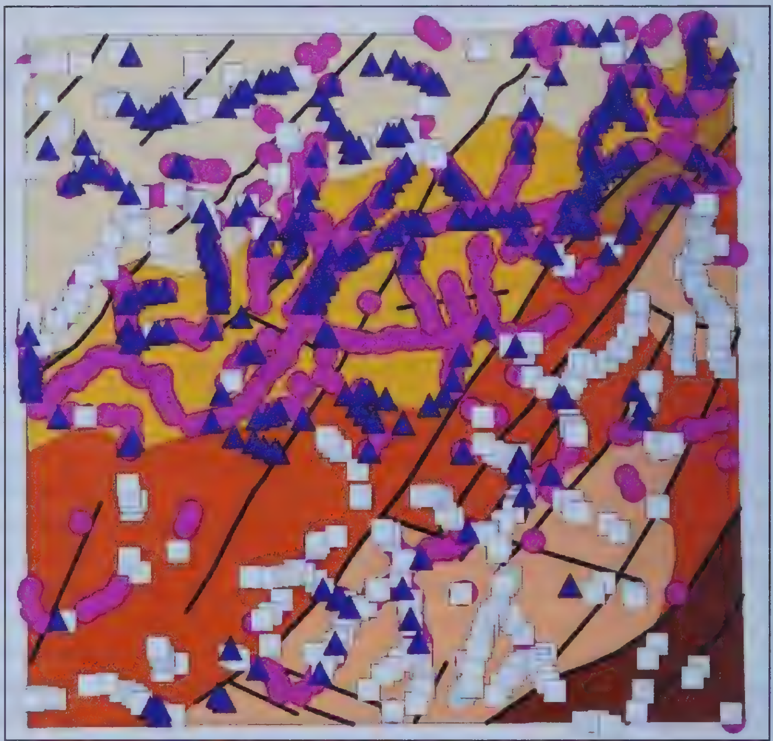

Figure 4. Data queried from the field database can be extremely useful in differentiating lithologies. In this Alaskan example, metamorphic units can largely be recognized by their relative abundance of garnet (pink circles), relict sandstone grains (white squares), and carbonate (blue triangles). Map area is about 14 by 14 miles.

able for purchase the following year; however, testing multiple brands and generations of equipment and software is prohibitively expensive.

DGGS is currently field testing Samsung's Q1P SSD and Q1U-SSDXP tablet computers, the 12-channel DeLorme Earthmate BT-20 GPS, and the Kodak Easyshare V610 camera (discontinued product). (Note: Models listed are not necessarily all-inclusive of those potentially capable of meeting requirements for field entry of geologic data. Brand names are examples only and do not imply endorsement by the State of Alaska.) The full list of gear includes the computer, two 6-cell computer batteries, stylus, computer case, sealable plastic bags, screen protector, shoulder strap, GPS with extra battery, camera, mini tripod, and other camera accessories (fig. 5). The Q1P SSD units and all supporting equipment weigh 3.9 lbs. The Q1U-SSDXP units and all supporting equipment weigh 4.2 lbs.

Figure 5. Q1P SSD tablet and supporting digital mapping equipment.

Table 1. DGGS's digital mapping requirements for hardware and software. Samsung's Q1 series does not have the features shown in italics. Some features may be added or configured with extra hardware or software.

Essential features

- Intuitive to learn and easy to use.
- Screen about 5" x 7"—compact but large enough to see map features.
- Lightweight—must be less than 3 lbs.
- *Rugged, as typically defined by military standards and ingress protection ratings.*
- Waterproof
- Transcription to digital text from handwriting and voice recognition.
- Can store paragraphs of data (text fields).
- Can store complex databases with dropdown lists.
- *Screen is easy to read in bright sunlight and on gray sky days* (could be configured).
- Removable static memory cards can be used to back up data.
- Chargeable by unconventional power sources (generators, solar, etc.).
- Wireless real-time link to GPS.
- Can change batteries in the field.
- Operating system and hardware are compatible with robust GIS program.

Important features

- USB port(s)
- *Protective case* (can be purchased separately for Q1U-SSDXP).
- At least 512 MB memory.
- Memory on board is recoverable.
- Batteries should have no "memory," such as with lithium ion.
- Wireless real-time link to computer, camera, and other peripherals.
- *Portable battery with at least 9 hours of life at near constant use.*
- *Real-time and post-processing differential correction for GPS locations* (could be configured).

Software being tested includes ESRI's ArcPad 7.1.1, Geologic Data Assistant (GDA) extension for ArcPad (Thoms and Haugerud, 2006), Microsoft's Access and OneNote, and EverNote's RitePen. ArcPad and GDA are GIS software that work together with a GPS in real time to show the geologists' current location or to digitize new features on-screen. GDA, an ArcPad extension created for geologic mapping, has been upgraded from ArcPad 6.0.3 to version 7.1.1. DGGS is testing OneNote as a container for photographs, annotation, sketches, and narratives, and for its text recognition capability. Access houses the field database and is being tested as a field application. RitePen is a "write anywhere" handwriting recognition program that allows text entry in Access forms, as well as in many other programs.

Digital Mapping Computer

Two hardware requirements stood out as particularly important for the digital mapping computer—screen size and weight. Weight, in particular, is of tremendous concern. At the end of a field day, DGGS minerals geologists already regularly carry 80 lb of gear and rocks. From the computers and PDAs available in 2007, Samsung's Q1P SSD met the most requirements for our first attempt at digital mapping. Rejected options included PDAs because of their small screen size and lack of computing power, and rugged laptops and rugged tablets because of their heavier weight.

The Samsung Q1P SSD is a small but powerful tablet PC that runs Windows XP Tablet PC Edition. Its predecessor, Samsung's Q1, was one of the first Ultra-Mobile PCs (UMPC) launched in 2006 in response to Microsoft's Origami Project, a challenge to manufacturers to make a small, touch-screen computer, optimized for mobility. Since then, Samsung has offered several redesigned iterations of the computer, two of which are the Q1P SSD (discontinued product), and the Q1U-SSDXP (or Q1 Ultra SSDXP). DGGS is currently field testing two each of these computers. Both of the UMPCs feature a 32 GB solid state (NAND flash memory) hard drive. Hence, the computer does not have a spinning hard drive, is more resistant to damage from accidental drops than those with spinning hard drives, and creates less heat when operating. Additionally, battery life is significantly increased because a motor is not required to constantly spin the hard drive. Both computers also have a 7-inch screen and weigh less than 2 lbs with the extended 6-cell battery. See table 2 for their specifications.

For use as a DGGS field computer, the biggest drawbacks of the Q1 series are their limited ruggedness and lack of waterproofing. Custom carrying cases were locally manufactured by Apocalypse Design, Inc. for the Q1P SSD tablets that add protection from drops and contact with rocks. The case has a plastic shield to protect the tablet's writing surface, mesh fabric that allows air circulation, and several tabs to attach carrying straps. The Q1U-SSDXP tablets have carrying cases manufac-

Table 2. Selected specifications for the Q1P SSD and Q1U-SSDXP from http://www.samsung.com/.

Feature	Q1P SSD	Q1U-SSDXP
Operating system	Windows XP Tablet Edition	Windows XP Tablet Edition
Processor	Intel Pentium M ULV, 1.0 GHz	Intel Ultra Mobile Processor A110, 800 MHz
Storage	32GB SSD	32GB SSD
Memory	1GB DDRII 533	1 GB DDRII 400
Graphics	Intel® Graphics Media Accelerator 900, 128 MB	Intel® Graphics Media Accelerator 950, 128 MB
Display	7" WVGA Touch Screen LCD, 800 x 480, 280 nits	7" WSVGA Touch Screen LCD, 1024 x 600, 300 nits
Communications	802.11b/g Wi-Fi, 10/100 Base-TX Ethernet, Bluetooth 2.0	802.11 b/g Wi-Fi, 10/100 Base-TX Ethernet, Bluetooth 2.0 + EDR
Ports	Two USB 2.0, One Type II CF card, Headphone Jack, VGA	Two USB 2.0, 2-in-1 Memory Slot (SD/MMC), Headphone Jack, VGA
Dimension	9.0 x 5.5 x 1.0 inches	8.96 x 4.88 x 0.93 inches
Weight with battery	1.7 lbs (with 3-cell battery)	1.4 lbs (with 4-cell battery)
Keyboard	N/A	QWERTY Key Pad
Camera(s)	N/A	Front Facing Video 300 P, Rear Facing Video/Still 1.3 MP

tured by OtterBox. The OtterBox 1990 Defender Case for Q1 Ultra UMPCs has a thermal-formed protective clear membrane to protect the writing surface, a high-impact polycarbonate shell, and a silicone layer that covers the unit and its ports. Both cases provide some water resistance but do not make the tablets waterproof.

Although inherently problematic, sealable plastic bags were determined to be the tablets' best protection against water intrusion. Concern about overheating problems due to lack of air flow in the plastic bags led to a series of heat tests. A Q1P SSD tablet was set up with a program that measures ambient air temperature, graphics processing unit (GPU) temperature, memory temperature, and CPU die-core temperature. To ensure that the computer generated the most heat possible, a process was activated that writes to and then erases 80 percent of the available memory while drawing random polygons on the screen, and that uses leftover CPU cycles to compute the square root of a random 25 digit number.

The computer was placed in a sealed plastic bag, and its temperatures were monitored over the life of the standard 3-cell battery while the computer was located at room temperature and then in a 150°F oven. Then the computer was turned off, placed in its sealed bag, and chilled overnight in a -25°F freezer. In the morning, the heat-generating processes were restarted. The computer was placed back in a sealed plastic bag and again in the oven at 150°F until the battery ran down. While the CPU did in fact slow down during these tests, it never faltered, never shut down, and never melted. The computer's self-preservation mechanism (based on temperature) slowed the processor down to slower and slower speeds in order to consume less power, thereby creating less heat.

2007 Field Test

During the summer 2007 field season, two geologists using Q1P SSD tablets tested the digital mapping equipment for one day. Hardware and setup issues included poor screen visibility in bright sunlight (fig. 6) and Bluetooth connection problems with the camera. It was feasible but inconvenient to cover the computer with two layers of plastic (case and sealed plastic bag) while trying to operate the buttons, and the plastic layers made screen-viewing more difficult.

In a similar field situation with Samsung Q1P series computers, Alaska Division of Forestry (DOF) field personnel had difficulty maintaining consistent Bluetooth GPS connections. DOF prefers built-in GPSs. Their temporary solution is to use external plug-in CF GPS receivers; however, field personnel have broken off two external antennas during normal use. DOF solved the screen visibility problem by replacing their computers' screens (3 Q1P and 2 rugged laptops) with Advanced Link Photonics, Inc. resistive touch transflective LCD screens (Thomas Kurkowski, oral commun., 2008). The enhanced resistive touch screens reduce glare from 10 to 20 percent on regular screens to 1 percent reflected light, and the LCD screens are transflectively upgraded and often brighter with an increase in nits by 10–30 percent (Advanced Link Photonics, Inc., oral commun., 2008).

Software issues included frequent virus software popup messages, problems recording lengthy text and with text recognition in Microsoft OneNote, and GDA incompatibility with DGGS-style field notes. In general, more time needs to be spent setting up an easy-on, automatically configured interface for field geologists so there are no or minimal technical details to manage in the field. To truly have a seamless field data entry system requires a customized, form-based, GIS-database interface.

2008 Field Test

Several personnel from DGGS Mineral Resources and Engineering Geology sections are currently testing the Q1P SSD and Q1U-SSDXP field computers. In 2008, the Access field database was replicated and placed on the tablets for direct data entry. RitePen text recognition software was provided for data entry into the Access form. Staff set up ArcPad with project GIS files to automatically load with the program, and configured GPSs with Bluetooth to provide location information to ArcPad and GDA. A Bluetooth camera was also configured to add pictures to Microsoft OneNote, where they will be annotated.

Initial impressions are that the digital mapping hardware and software were better configured this year than in 2007, but that the geologists were not adequately prepared to use the equipment. Most geologists were not familiar enough with the tablet computers, Access database, new GPSs, and how the text recognition software worked to complete meaningful field data entry. Geologists were also fearful that they would damage the hardware and were reluctant to carry it, especially in inclement

Figure 6. Surficial geologists Dick Reger (bottom left) and Trent Hubbard (under tarp) attempt to minimize screen glare and protect unit from rain while working.

Figure 7. Geologist Trent Hubbard successfully records geologic data digitally.

weather. Thus far, positive feedback includes good performance by the RitePen text recognition software, seamless GPS connectivity via Bluetooth, good performance by the system overall as a navigational aid in the helicopter, successful capture of geologic contacts and attribute data (fig. 7), and potential use of the computer as a pocket handwarmer.

FUTURE OF DIGITAL MAPPING AT DGGS

Before the next field season, interested DGGS geologists will spend more time learning to use the computers and software so that they are comfortable enough with them to collect at least several days' worth of data in the field. For 2009, there will probably only be minor changes to the configuration of the computers. New daylight readable screens may be the biggest potential improvement in the system.

In the long term, some significant software changes are necessary to truly make digital mapping viable. The biggest hurdle will be creating a simple, user-friendly, form-based interface in ArcPad that can capture GIS features as well as detailed geologic data at field stations. Before that can happen, however, we must migrate the Access database to ESRI ArcMap, and then serve the data out to ArcPad.

In conjunction with the move, the field database will probably be redesigned to more closely match the structure of DGGS's enterprise Oracle database (Freeman and others, 2002; Freeman and Sturmann, 2004). The redesign, development of data loading routines, and decisions about data flow and editing could start in mid 2009. To date, only basic station and sample field data from recent projects have been entered into the enterprise database. DGGS has had little time and no dedicated funding to perform this task. With the field database redesign, we hope that after the data have been quality controlled, it will be a fairly simple matter to load all of the data into the Oracle database.

The next step, creation of the data entry form using ESRI's ArcPad and ArcPad Application Builder, could begin in 2010. Design of the form will also require Visual Basic Scripting, possibly developed with the help of an outside contract. The interface will be designed for geologists' ease of use and could be field tested as early as 2011.

CONCLUSIONS

DGGS recognizes that the current methodology of geologic mapping can be more efficient, especially in the way field data are recorded. DGGS minerals geologists currently write field station and sample observations on note cards, which are later entered into an Access database by a student intern. In the past, data entry by student interns has taken up to seven months. Given the limited amount of time available to complete mapping projects, this excessive period of data entry is unacceptable.

DGGS is considering digital mapping as a way to streamline the mapping process. To that end, we are evaluating the effectiveness of entering field-geologic observations directly into an Access database and GIS software on Samsung ultramobile tablet computers. Brief field tests in 2007 and 2008 suggest that the equipment and software have the potential to work as a digital mapping system, but that significant work is still needed to create a system that will facilitate comfortable data entry by field geologists.

We will continue to work on new solutions and keep an eye out for new technology that will help alleviate some of the problems discovered thus far, including limited ruggedness and lack of waterproofing of the units. In the next couple of years, DGGS will train additional geologists on the computers and software so that we can then conduct more comprehensive field tests. Future plans include migration of the field database to ESRI's ArcMap and ArcPad, and creating a user friendly GIS-database data-entry interface. Through sharing ideas and results, we anticipate that it will be possible to create a DGGS-wide digital mapping system capable of benefiting all of the field projects. If the process proves effective, we anticipate that within a few years most DGGS geologists will be out on the outcrop with little field computers, happily, but more efficiently, creating geologic maps, reports, and digital data to better serve the public's needs for resource evaluation, hazards identification, and well informed land-use management.

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Dear Readers:

Fall is a time for reflection, which can be both satisfying and unsettling. When I look around home at the many half-finished projects that will soon be covered by snow; it is an unsettling moment. When I look at what the staff at DGGS has accomplished this past summer, even with all the marginal weather we experienced this year, I am overly satisfied and proud. This short column is not the place to go through all the DGGS activities, and I encourage you to visit our website at http://www.dggs.dnr.state.ak.us/ and download our 2008 Annual Report when it is posted in January, but I would like to at least give you a sneak preview.

The pipeline corridor project completed the next-to-last phase of geologic mapping and neotectonic analysis between Delta and Tok. The energy group finalized the Bristol Bay program, finished mapping in the Sagavanirktok area, and completed two short field programs in the Cook Inlet region. The minerals group dodged clouds and snowstorms and mapped some exciting geology in the north-central Alaska Range where they are making great strides in deciphering the bedrock geology and structure in the eastern Bonnifield area and along the proposed pipeline corridor. The engineering geology group took the lead on surficial mapping in nearly all the field areas and spearheaded an impressive array of field trip guidebooks associated with the Ninth International Conference on Permafrost. The publications section kept all the data flowing through to our customers. The volcanology group has been especially busy with fieldwork and unprecedented eruptive activity out on the Aleutian Chain. Yes, a lot has been accomplished here at DGGS since my last writing.

We also have a number of personnel transitions of note. We have hired a new Quaternary mapper in the engineering geology group, Trent Hubbard, and a new geologist in our minerals section, Joe Andrew. Joe's expertise is in structural geology and tectonics in metamorphic and igneous terrains. Jean Riordan has rejoined the Geologic Materials Center in Eagle River and is helping us get a searchable database for our collection on the web. We are very excited to have these new geologists join us. We also have a number of great student interns without whom we would not be able to get it all done. Geologists Paige Delaney, Ken Papp, Susan Brown, and Sharon Hansen all moved on to new horizons and we wish them great success in their new roles.

I won't say much about the challenging times that we are all living through given the big changes in energy and economic stability of the U.S. Clearly, we will all be faced with some very important decisions concerning the short- and long-term stability of our state and the nation. What I will say is that DNR, and DGGS, are engaged at all levels trying to address the difficult issues in energy and resource development, and public safety from geologic hazards across the state, for the benefit of all citizens.

Please stop by our offices if you would like to discuss, or get information on, any of the current or potential DGGS activities,

Regards,

Bob Swenson
State Geologist & Director

NEW DGGS PUBLICATIONS

GEOPHYSICAL MAPS & REPORTS

GPR 2006-8. Final processed database for the airborne geophysical surveys of the Alaska Highway corridor, east-central Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 disk. 1 DVD $15.

GPR 2008-3. Line, grid, and vector data, and plot files for the airborne geophysical survey of the Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 27 sheets, 1 disk. 1 DVD. Supersedes GPR 2008-2. Download the digital data free of charge. $15.

GPR 2008-3-1A. Total magnetic field of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-1B. Total magnetic field of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-1C. Total magnetic field of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-2A. Total magnetic field of the western Styx River Survey, southcentral Alaska, by Burns, L.E., 2008, 1 sheet, scale 1:63,360. Magnetic contours included. $13.

GPR 2008-3-2B. Total magnetic field of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Magnetic countours included. $13.

GPR 2008-3-2C. Total magnetic field of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Magnetic contours included. $13.

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GPR 2008-3-3B. First vertical derivative of the total magnetic field of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-3C. First vertical derivative of the total magnetic field of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-4A. 56,000 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-4B. 56,000 Hz coplanar apparent resistivity of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Inc., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

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GPR 2008-3-5A. 56,000 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-5B. 56,000 Hz coplanar apparent resistivity of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-5C. 56,000 Hz coplanar apparent resistivity of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-6A. 7200 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

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GPR 2008-3-7A. 7200 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-7B. 7200 Hz coplanar apparent resistivity of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-7C. 7200 Hz coplanar apparent resistivity of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-8A. 900 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-8B. 900 Hz coplanar apparent resistivity of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-8C. 900 Hz coplanar apparent resistivity of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Ma.nagement Corp., 2008, 1 sheet, scale 1:63,360. Topography included. $13.

GPR 2008-3-9A. 900 Hz coplanar apparent resistivity of the western Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-9B. 900 Hz coplanar apparent resistivity of the southern Styx River Survey, southcentral Alaska, by Burns, L.E., Fugro Airborne Surveys Corp., and Stevens Exploration Management Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-3-9C. 900 Hz coplanar apparent resistivity of the eastern Styx River Survey, southcentral Alaska, by Burns, L.E., and Fugro Airborne Surveys Corp., 2008, 1 sheet, scale 1:63,360. Resistivity contours included. $13.

GPR 2008-4. Linedata and gridded data for the aeromagnetic survey of the Holitna basin area, western Alaska: Parts of the Lime Hills and Sleetmute quadrangles, by Burns, L.E., SIAL Geosciences Inc., and On-line Exploration Services Inc., 2008, 1 sheet, 1 disk. 1 CD-ROM. http://www.dggs.dnr.state.ak.us/GPR2008-4/ Download the digital data free of charge. $10.

NEWSLETTER

NL 2008-1. Alaska GeoSurvey News, by DGGS Staff, 2008, 14 p. Free.

PRELIMINARY INTERPRETIVE REPORT

PIR 2008-1. Preliminary results of recent geologic field investigations in the Brooks Range Foothills and North Slope, Alaska, by Wartes, M.A., and Decker, P.L., 2008, 206 p. $112.

- PIR 2008-1A. Overview of recent geologic field investigations, North Slope and Brooks Range foothills, Alaska, by Wartes, M.A., and Decker, P.L., 2008, 1 sheet.
- PIR 2008-1B. Measured section and facies analysis of the Lower Cretaceous Fortress Mountain Formation, Atigun syncline, northern Alaska, by Wartes, M.A., 2008, 1 sheet.
- PIR 2008-1C. Evaluation of stratigraphic continuity between the Fortress Mountain and Nanushuk Formations in the central Brooks Range foothills–Are they partly correlative?, by Wartes, M.A., 2008.
- PIR 2008-1D. Measured sections and preliminary interpretations of the Nanushuk Formation exposed along the

Colville River near the confluences with the Awuna and Killik rivers, by LePain, D.L., Decker, P.L., and Wartes, M.A., 2008, 4 sheets.

PIR 2008-1E. Geochemistry of the Aupuk gas seep along the Colville River–Evidence for a thermogenic origin, by Decker, P.L., and Wartes, M.A., 2008.

PIR 2008-1F. Stratigraphic and structural investigations in the Ivishak River and Gilead Creek areas: Progress during 2007, by Decker, P.L., Wartes, M.A., Wallace, W.K., Houseknecht, D.W., Schenk, C.J., Gillis, R.J., and Mongrain, J., 2008, 1 sheet.

PIR 2008-1G. Turonian-Campanian strata east of the Trans-Alaska Pipeline corridor, North Slope foothills, Alaska: Progress during the 2001-02 and 2007 field seasons, by LePain, D.L., Kirkham, Russell, Gillis, R.J., and Mongrain, J., 2008.

PIR 2008-2. Jurassic through Pliocene age megafossil samples collected in 2005 by the Alaska Divison of Geological & Geophysical Surveys from the Bristol Bay–Port Moller area, Alaska Peninsula, by Blodgett, R.B., Finzel, E.S., Reifenstuhl, R.R., Clautice, K.H., Ridgway, K.D., and Gillis, R.J., 2008, 12 p. $2.

PIR 2008-3C. Reconnaissance interpretation of permafrost, Alaska Highway corridor, Delta Junction to Dot Lake, Alaska, by Reger, R.D., and Solie, D.N., 2008, 10 p., 2 sheets, scale 1:63,360. $28.

RAW DATA FILES

RDF 2008-3. Preliminary bathymetric map of Mother Goose Lake, Alaska Peninsula, by Schaefer, J.R., Wallace, K.L., and Kassel, C.M., 2008. Free.

RDF 2008-4. 40Ar/39Ar ages from the Tyonek D-6 Quadrangle and parts of the Tyonek D-7, Tyonek D-5 and Tyonek C-6 quadrangles, Alaska, by Layer, P.W., and Solie, D.N., 2008, 14 p. $2.

REPORT OF INVESTIGATIONS

Reger, R.D., Burns, P.A.C., and Staft L.A., 2008, Surficial-geologic map of the Salcha River – Pogo area, eastcentral Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations 2004-1C, 1 sheet, scale 1:63,360.

SPECIAL REPORTS

SR 62. Alaska's Mineral Industry 2007, by Szumigala, D.J., Hughes, R.A., and Harbo, L.A., 2008, 89 p. Free.

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Vol. 12, No. 1, April 2009

The Alaska Geologic Materials Center

John W. Reeder[1]

The Alaska Geologic Materials Center (GMC) is Alaska's "public rock library," and is ranked as one of the largest and most diverse rock collections anywhere (fig. 1). It consists of Alaska surface rock, soil, and archeological samples as well as subsurface rock cuttings and core from oil and gas wells (fig. 1; fig. 2), groundwater wells, mineral holes (fig. 1), and engineering test holes. The collection also includes a huge number of corresponding processed scientific materials such as petrographic thin sections and paleontological microscope slides that were derived from these samples. The facility is northeast of Eagle River off the Glenn Highway at 18205 Fish Hatchery Road, about 18 miles from downtown Anchorage (www.dggs.dnr.state.ak.us; see GMC link).

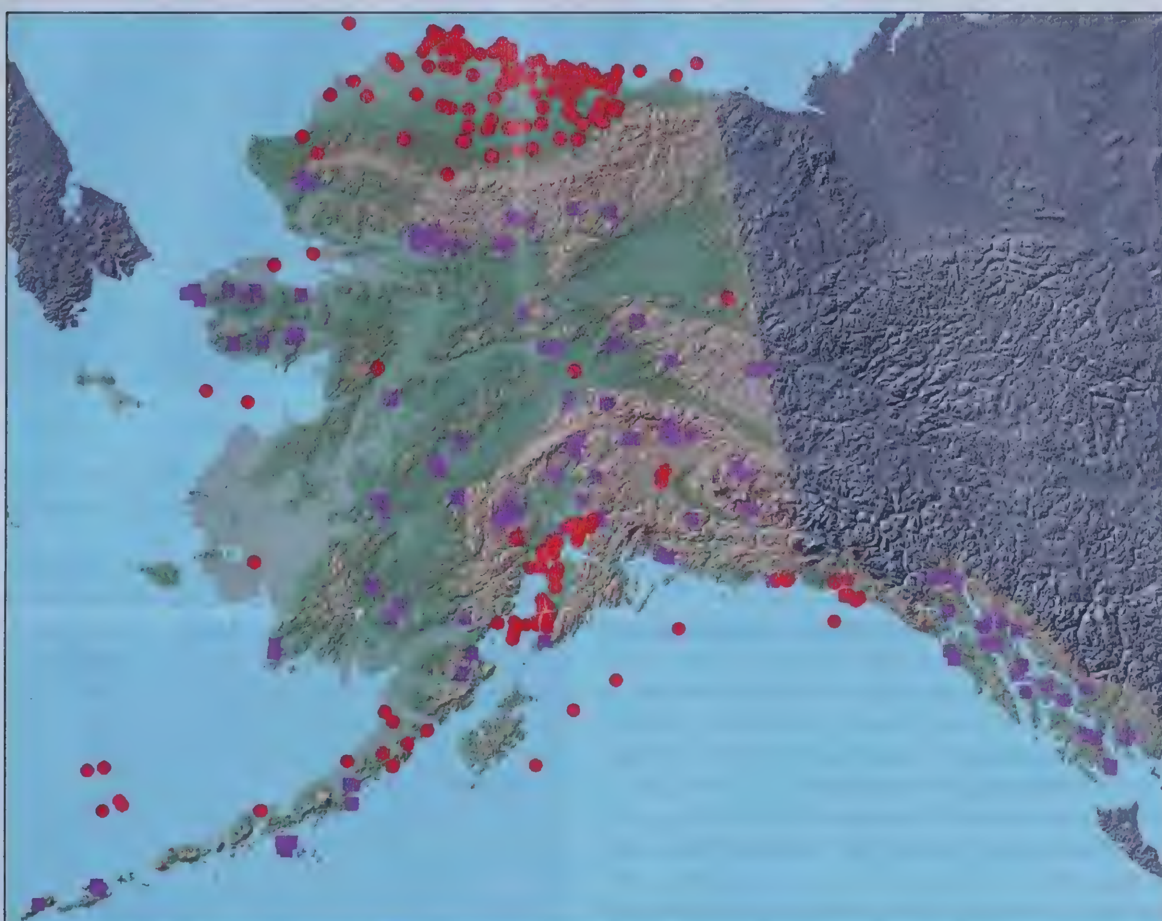

Figure 1.

[1]Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks Alaska 99709-3707
Email: john.reeder@alaska.gov

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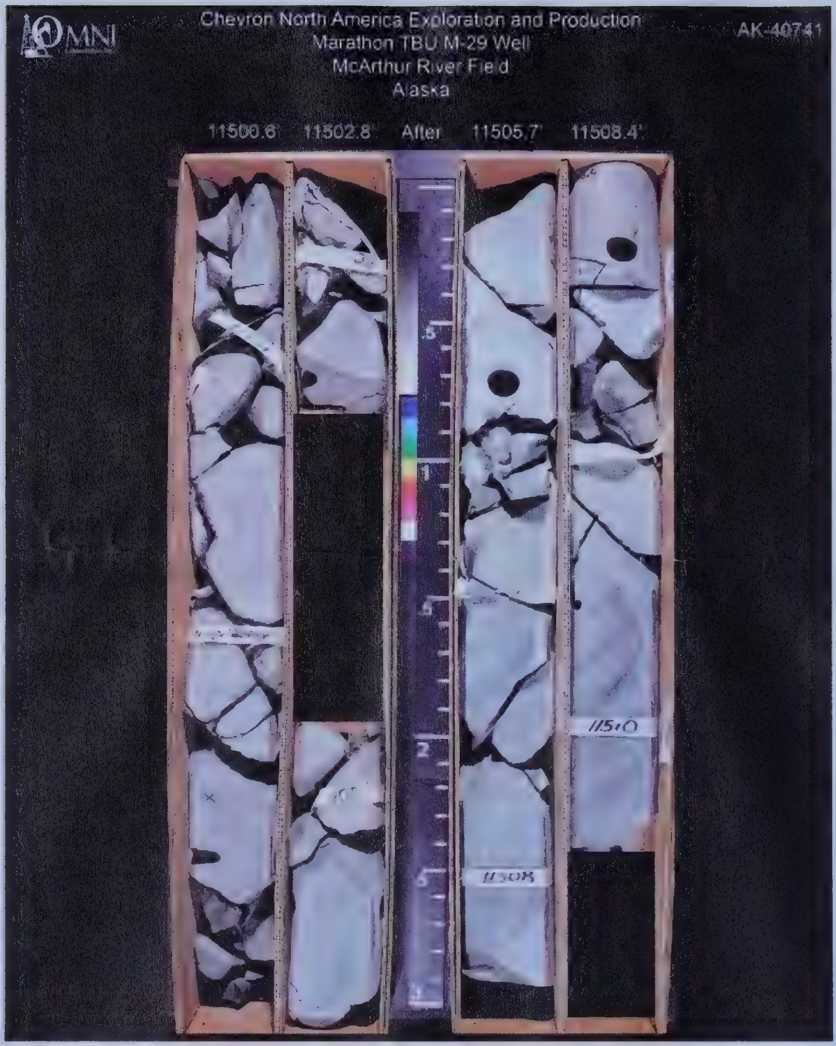


Figure 2.

The GMC contains many unique specimens available for examination. Some of the more noteworthy examples are:

- original rock samples from the Atlantic Richfield Prudhoe Bay No. 1 discovery well
- oil samples from the Prudhoe Bay reservoir
- original rock samples from the Swanson River discovery oil wells of the Kenai Peninsula
- gold-bearing quartz veins of the historical Treadwell Mine of the Juneau area
- copper sulfide-bearing cores of the Nikolai Prospect near the historical Kennecott Copper Mine
- beautiful Jurassic ammonites from Fossil Point (fig. 3)
- rare orbicular diorites from the Talkeetna Mountains (fig. 4)
- famous almandine garnets in schist from Wrangell (fig. 5)

The microfossil collection alone is one of the largest collections of its type, attracting scientists from all over the world to view it. It consists of more than 200,000 glass slides of palynomorphs (fig. 6), Foraminifera, siliceous microfossils, and nannoplantons, to name just a few. Nearly all geologic resource exploration in Alaska, by necessity, starts at the Alaska GMC.

At every corner of the facility and on every shelf, the Alaska GMC represents the natural and human history of Alaska. It contains materials from more than 22 government agencies and institutions, universities, and private companies. The GMC is managed by the Alaska Department of Natural Resources' Division of Geological & Geophysical Surveys (DGGS), which established cooperative agreements with the U.S. Geological Survey (USGS; February 1982), the Alaska Oil and Gas Conservation Commission (May 1985), the U.S. Bureau of Mines (1987), the U.S. Minerals Management Service (July 1986), and the U.S. Bureau of Land Management (November 1993).

Two individuals were principally responsible for creating the important first GMC cooperative agreement: former State Geologist **Ross G. Schaff** of DGGS and former Western Region Director's Representative **George Gryc** of USGS. This important agreement was signed February 6, 1982. The official date of the opening of the Alaska GMC was December 12, 1984, at its current location in Eagle River.

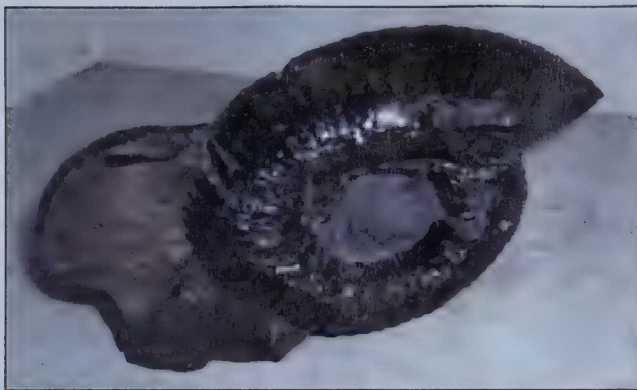


Figure 3.

Figure 4.

Figure 5.

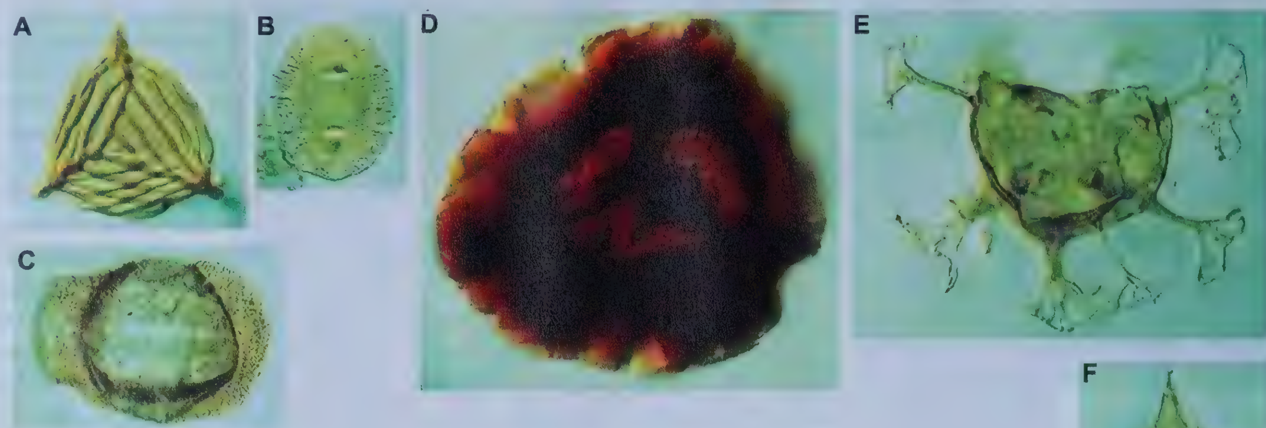
The GMC site, which currently occupies an 11.4-acre lot on the north side of Fire Lake Creek, was originally designed to be a federal fish hatchery; it was transferred to the State of Alaska shortly after statehood in 1959. With a $1.5 million loan from the U.S. Fish and Wildlife Service to the State of Alaska Department of Fish and Game, major expansion of the facility was undertaken in the 1970s, expanding it into one of Alaska's major fish hatcheries. The hatchery was abandoned because of water supply and water contamination problems in the late 1970s and was turned over to the Department of Natural Resources with the understanding that DGGS would, for the USGS, store the federal National Petroleum Reserve–Alaska core at the site. The USGS contributed $300,000 toward rehabilitating the facility, adding extensive shelving, and then transferring rock materials to it with the help of William (Doc) L. Adkison (USGS) and William (Bill) Lyle (DGGS). Mitch Henning of DGGS became the first GMC curator; Dr. John W. Reeder was appointed curator in July 1987 by then-State Geologist Robert B. Forbes.

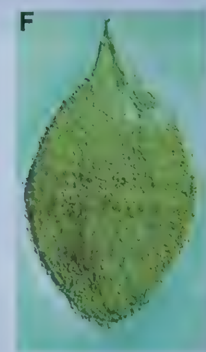
The cooperative agreements that established the facility required the establishment of a GMC Advisory Board, which was created in 1987 for the main purpose of helping DGGS support, manage, and protect the publicly available GMC collection. The Board consists of the Alaska State Geologist, a representative from each cooperating agency, a representative from the oil and gas industry, and a representative from the mining industry. Between 1987 and 1990, this Advisory Board, chaired by Don Hartman of Texaco Inc., created the Alaska GMC Operating Policy, which defines the dos and the don'ts for the GMC curator and users. Such a policy statement is critical for the successful operation and protection of any public archive.

The opening of the doors on December 12, 1984, was the beginning of the Alaska Geologic Materials Center. However, Alaska rock samples had been publicly available for examination and testing earlier through the Alaska Oil and Gas Conservation Commission (originally part of the Alaska Department of Natural Resources, Division of Mines and Geology).

The Alaska Constitution grants the State of Alaska management ownership of all subsurface fluid and gas resources (oil, gas, geothermal fluids, and water). Alaska Administrative Code 20 AAC 25.071 requires representative rock samples from oil and gas wells to be turned over to the State. After two years of being held confidential, samples become available for public examination. Before the GMC was established, the Alaska Oil and Gas Conservation Commission (AOGCC) held these oil and gas well samples. Companies such as the American/Canadian Stratigraphic Company examined many of the samples. Many of the oil companies expressed the need to not just examine, but to also test parts of the samples for additional information. Many geologists, such as Anchorage-based Alexander Sisson of the former Union Oil Company of California (Unocal), argued that by undertaking such testing, "We would learn more than we would by just examining the samples."

Alaska Department of Natural Resources' former Chief Petroleum Geologist Thomas R. Marshall, Jr., finally agreed in 1972 to allow testing of parts of the samples on the condition that all results including data, slides, and residues, were returned





A. *Plicatella sp* – Fern spore from the middle-Cretaceous Nanushuk Formation
B. *Wodehouseia quadrispina* – Angiosperm (flowering plant) pollen from the latest Cretaceous Canning Formation
C. *Lunatisporites noviaulensis* – Gymnospermous pollen from the earliest Triassic Eileen Shale
D. *Labiadensites fimbriatus* – Terrestrial plant spore of unknown affinity from the Mississippian Kekiktuk Formation
E. *Oligosphaeridium pulcherrimum* – Marine dinoflagellate cyst from the Early Cretaceous Kalubik Formation
F. *Pareodinia sp.* – Marine dinoflagellate cyst from the Jurassic Kingak Formation

Figure 6.

and made available to the public. Tom appointed William Van Alen the difficult job of monitoring all sampling and ensuring the return of all materials and data. As a result, the first 60 GMC data reports and 50,000 microfossil and petrographic slides (mostly from Unocal) were received and archived by AOGCC. Available space for public examination and sampling was limited at the AOGCC facility and they realized expansion was needed. Their cooperative agreement with DGGS was signed in 1985.

Since 1984, all GMC samples have been available to the public for examination and additional testing or processing under "GMC policy requirements." The GMC has been predictably busy, servicing an average of about 450 physical visitations per year (fig. 7) by professionals from industry, government agencies, academia, and the public. This number is high compared to other rock depositories; however, the number of visitations per year is fairly constant and seems to be independent of oil or mineral economies. The collection has expanded continually (fig. 9), apparently independent of industry economies.

GMC's collection of new representative samples from oil and gas wells grows annually by about 30 wells (fig. 8); about 25 new mineral holes are added each year (fig. 8). Mineral hole accessions vary considerably because no regulations require such samples to be turned in to a public depository. Instead, all mineral hole samples are received as voluntary donations. Most of the oil and gas well collection at the GMC has also been received as voluntary donations from industry. Such sample donations help supplement the existing cuttings and core chips that were required in the AOGCC collection at the GMC. The extra donated samples allow much more extensive testing, resulting in more rapid growth of processed samples and data reports.

The most sample donations to the Alaska GMC occurred in fall and winter of 1997 when 17 tractor-trailer loads of materials were received, including:

- 14 truckloads from Shell Oil Company (Houston, TX)
- One-half truckload from Marathon Oil Corporation (Denver, CO)
- One truckload of U.S. Geological Survey NPRA well and shot-hole samples (Menlo Park, CA)
- One-half truckload of Jonesville mine coal holes (Palmer, AK)
- One truckload of Death Valley core holes (Seward Peninsula, AK)

The second largest donation arrived in the fall and winter of 2002 with 11 tractor-trailer loads from British Petroleum, including their Amoco collection from Tulsa and Houston and part of their Milne Point collection from Alaska. Two additional tractor-trailer loads of mineral core were also received from the University of Alaska Fairbanks. Three and one-half truck loads of oil/gas well and core hole samples were received during fall 2008.

The GMC's main and most complete oil/gas well sample collection for Alaska is the AOGCC collection. Of the hard-rock minerals housed at the GMC, the U.S. Bureau of Mines collection is the most complete. However, there are other important collections at the GMC, including:

- U.S. Minerals Management Service outer continental shelf collection

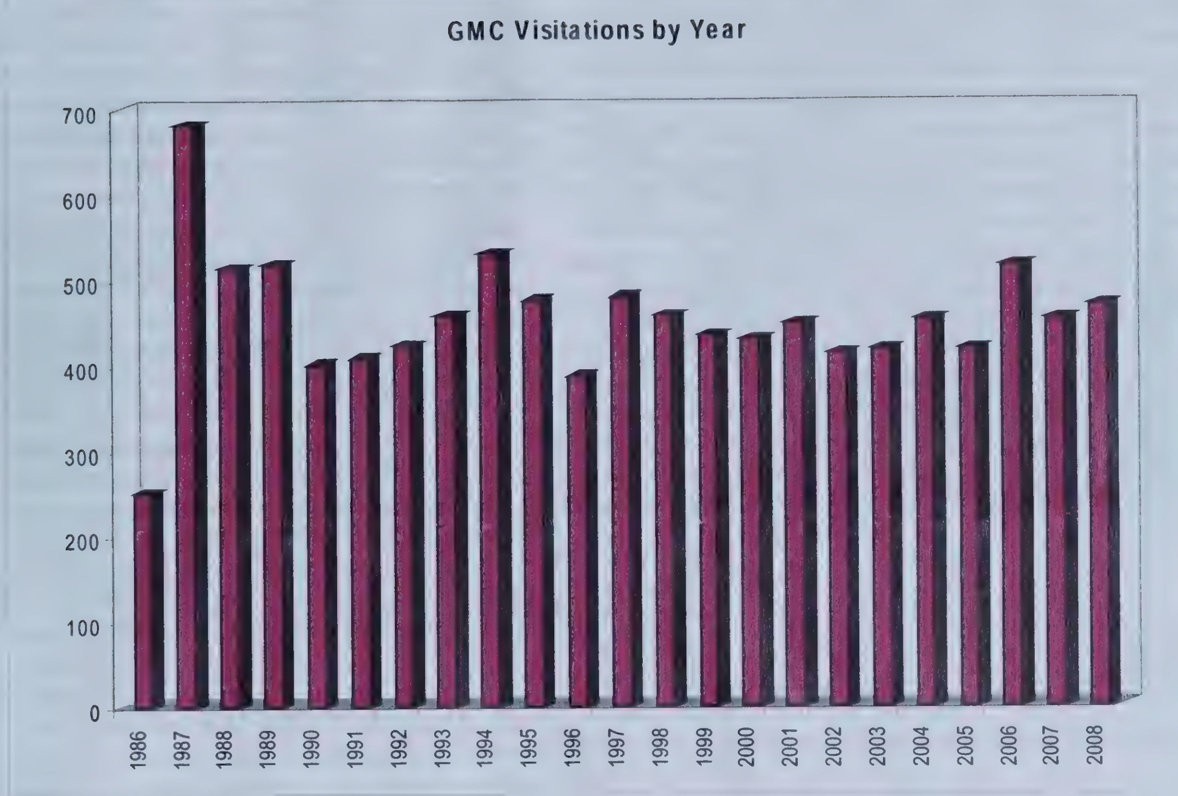


Figure 7.

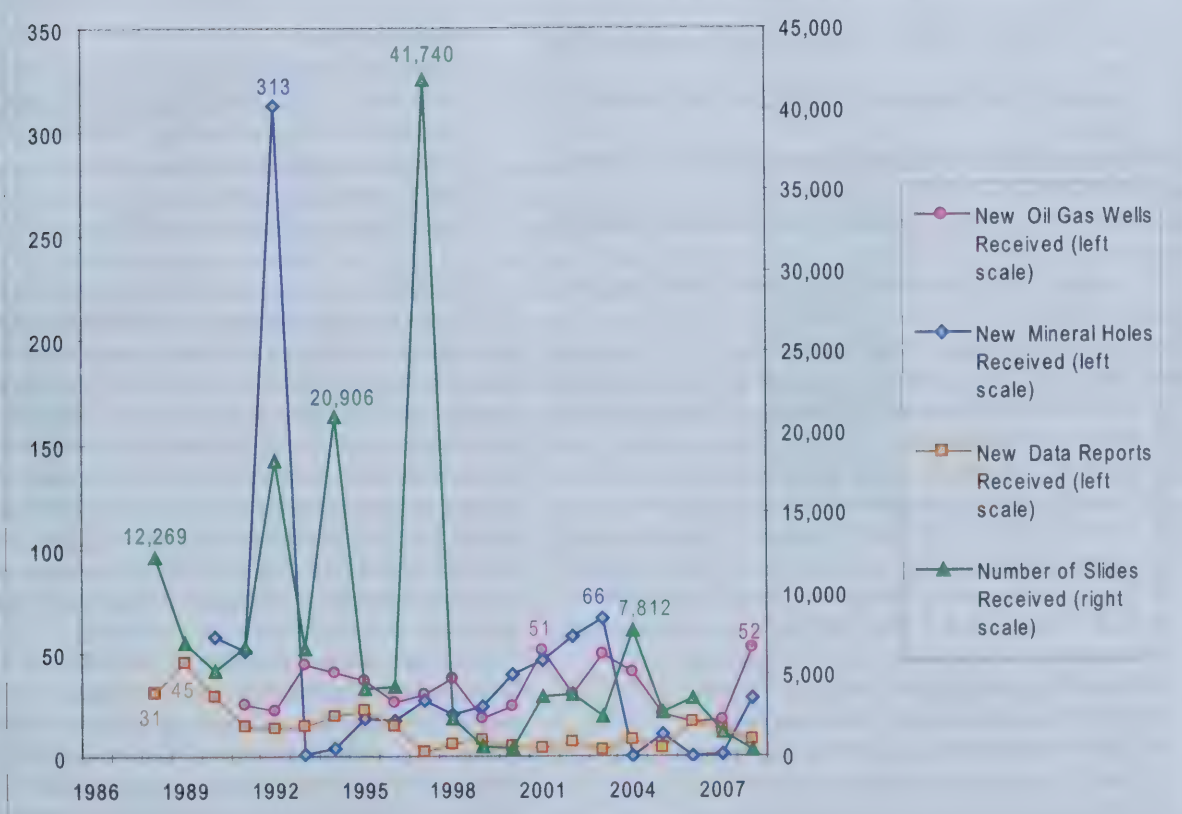


Figure 8.

Figure 9.

- ♦ U.S. Geological Survey oil and gas well sample collection
- ♦ Bureau of Land Management oil and gas well sample collection
- ♦ State of Alaska DGGS and Division of Oil & Gas surface sample collections
- ♦ Amoco Production Company well (from British Petroleum)
- ♦ Company geological reports, surface sample, and megafossil collections
- ♦ British Petroleum Milne Point and Badami well sample collections
- ♦ Cook Inlet Region, Inc. (CIRI) mineral hole and oil/gas well sample collection
- ♦ Forest Oil Corporation well sample collection
- ♦ Marathon Oil Corporation well sample collection
- ♦ OXY USA Inc. (Occidental Petroleum Corporation) well sample collection
- ♦ Phillips Petroleum Company well sample collection
- ♦ Shell Western E & P Inc. well sample, surface sample, megafossil, and processed slide collections
- ♦ Unocal Corporation well sample collection
- ♦ Battle Mountain mineral hole collection
- ♦ Calista Corporation mineral hole collection
- ♦ Aleut Corporation core hole collection
- ♦ Kennecott Minerals core hole collection
- ♦ Anaconda Mining Inc.core hole and map collections (through CIRI)
- ♦ Bristol Bay Native Village mineral hole collection
- ♦ University of Alaska Fairbanks core hole collections (Museum, Civil Engineering, Petroleum Engineering, Department of Geology & Geophysics)
- ♦ ARCO Alaska Inc. collection
- ♦ John Reeder rock specimen collection

The GMC has cuttings and core representing approximately 11,712,000 feet of drilling from 1,519 Alaska oil and gas exploratory and production wells. There are also more than 229,926 feet of diamond drill mineral core from 1,111 exploratory holes from 189 mining prospects/developments. The GMC stores well samples for nearly all oil and gas exploratory wells in Alaska, and at least some core samples from nearly half of the known mineral prospects and developments in Alaska (Nokleberg and others, 1987; Alaska Resource Data File, http://ardf.wr.usgs.gov). If surface samples were included, all areas of Alaska would be represented and figure 1 would be so densely populated with symbols, it would be unreadable.

GMC samples are available to the public for examination and even for additional testing and processing, subject to GMC policy requirements. All resulting processed materials from such testing, such as microfossil slides and resulting technical data such as chemical reports, are added to the GMC collection. As a result, with donations, there are currently 357 data reports and 266,000 glass slides, excluding duplicate slides,

in the GMC collection. Both the numbers of data reports and processed slides have increased continuously since Curator John Reeder instituted record keeping, although the rate of acquisition for both has decreased significantly since 1997. Between 1988 and 1997, the GMC received an average of about 25 data reports (fig. 8) and about 10,000 processed glass slides per year excluding the Shell Oil Company glass slide donation of 1997 (fig. 8). Between 1997 and 2008, the Alaska GMC averaged about 6 data reports and about 5,000 processed glass slides per year. Because at least 75 percent of the GMC visitors represent oil and gas interests, this drop might reflect the maturity of the Prudhoe Bay and Kuparuk oil fields of northern Alaska. However, although the amount of processing of existing GMC samples appears to be less in the last 10 years than in the previous 10 years, the GMC visitations (fig. 7) have *not* decreased.

DGGS's Geologic Communications section staff in Fairbanks recently completed a project to post online the data reports that are housed at the GMC. The reports are now available through the DGGS publications database, http://www.dggs.dnr.state.ak.us/pubs/pubs.jsp. Work is underway on an online-searchable database of materials available at the GMC; completion of that project is anticipated by the end of 2009.

The GMC collection has grown to occupy five buildings and 60 portable metal containers at the Eagle River site. The current facility long ago ran out of space to adequately store new samples. The number of metal containers on site has grown from zero in 1987 to 60 in the current configuration, with no space for additional containers. The need for a larger, state-of-the-art facility has been so obvious to the many GMC users and cooperating agencies that an ad hoc committee in 2005 developed criteria for a new, expanded, and centralized Alaska GMC. In April 2006, members of this committee met with State and other national experts to establish guidelines for a formal concept study. The study was completed in 2006 by the State of Alaska Department of Transportation & Public Facilities. The concept study report is available online (http://www.dggs.dnr.state.ak.us/download/gmc_concept_study_august_2006.pdf)

Alaska's Geologic Materials Center currently contains the largest public collection of core, cuttings, processed slides, data reports, and rock and mineral samples for Alaska. Its importance for future exploration and scientific research is priceless. Investment in a new facility for the preservation and use of these materials is a sound investment in Alaska's future (Reeder, 2008).

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Dear Readers:

There is nothing like a winter in Fairbanks to get your attention. This one has been notably special with more of our beloved 'typical' cold weather snaps, sufficient darkness to keep vampires roaming the streets for most of the day, and of course the hundreds of exciting geologic brushfires to keep things from getting boring. We have had a number of notable events, including triple volcanic events out on the Aleutian chain, a precipitous drop in commodity prices (as well as the economy), and a number of national events and scientific discussions that keep the blood flowing on the cold winter nights.

One of the realities that transcends all of the current debates and discussions is that the most important source of data necessary to keep our hypotheses grounded is archived at the Geologic Materials Center (GMC). Whether you propose vast interpretive changes in the location of sequence boundaries of the Cretaceous strata in the Colville Basin, or climate-associated mitigation and determination of historic climatic shifts, or the metamorphic history in the area around Livengood, or the potential for chemical reaction and adverse diagenetic change to reservoir quality associated with injection of super-critical CO2, the GMC is the place to find that one piece of hard data that will help break the code or provide the necessary level of certainty. John Reeder, the author of this issue's feature article, has been the curator and manager there for many years, and is the reason we have a viable GMC. Please join me in congratulating John for a job well done.

Finally, I can't promise a new GMC building next year, but I can say we are closer than ever before, and would appreciate your support when the time is critical. I will let you know.

Regards,

Bob Swenson
State Geologist & Director

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EVIDENCE FOR LATE WISCONSINAN OUTBURST FLOODS IN THE TOK–TANACROSS BASIN, UPPER TANANA RIVER VALLEY, EAST-CENTRAL ALASKA

Trent D. Hubbard[1] and Richard D. Reger[2]

INTRODUCTION

In 2006 the Alaska Division of Geological & Geophysical Surveys began an investigation of the geology and geologic hazards in the proposed natural-gas pipeline corridor through the upper Tanana River valley (Combellick, 2006; Solie and Burns, 2007). Much of this work has involved reconnaissance geologic mapping along a 12-mi-wide (19.3-km-wide) corridor centered along the Alaska Highway between Delta Junction and the Canada border. While mapping in the Tanacross Quadrangle (fig. 1) in 2008, we investigated the Tok fan to better understand its development during the last major glaciation. Like Foster (1970) and Carrara (2006), we recognize older and younger parts of the broad, low-gradient fan. The western half is Donnelly (marine oxygen-isotope stage 2) in age and the inset eastern half is Holocene. Our discussion here focuses on development of the older fan surface.

Figure 1. Location of study area in Tanacross Quadrangle, Alaska.

TOK FAN MORPHOLOGY AND MATERIAL CHARACTERISTICS

The Tok fan, which occupies most of the Tok–Tanacross basin, was created by streams flowing from the Tok River valley (fig. 2). Although described as an alluvial fan (Williams, 1970, p. 43), this feature lacks properties typically attributed to alluvial fans, including high-value radial slopes, limited radial length, and planoconvex cross profile (Blair and McPherson, 1994, p. 454). The Tok fan is up to ~24 mi (~39 km) wide, has radii that vary in length from ~8 to ~26 mi (~13 to ~42 km), and the fan surface slopes from ~7.6 to ~21 ft/mi (~1.4 to ~4 m/km).

On the higher, older fan surface, a series of 3.3- to 10-ft-deep (1- to 3-m-deep) finger-like surface channels containing sand fills up to ~1 ft (0.3 m) thick, which are locally cross bedded, radiate from the mouth of the Tok River valley toward the fan margins. We measured loess covers that average ~6 in thick (~15 cm thick) but range from 2 to 22 in (5 to 56 cm) on the older fan surface. According to John Burnham (07/25/08, oral commun.), the cover of silt on the Tok fan east of the Glenn Highway Tok Cutoff is generally <12 in (<30 cm) thick, although locally the silt is up to 10 ft (3 m) thick, and the thickness of silt increases close to the Tanana River. A typical post-Donnelly soil profile is developed on this surface (fig. 3).

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(continued on page 2)

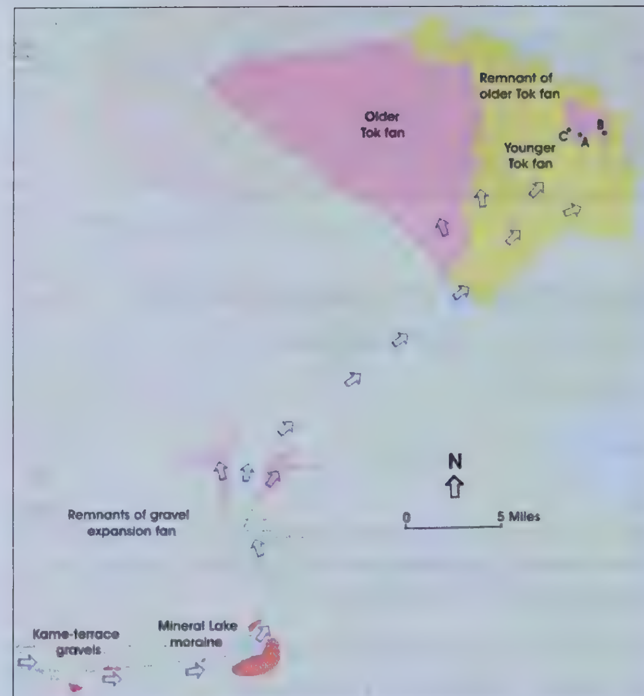
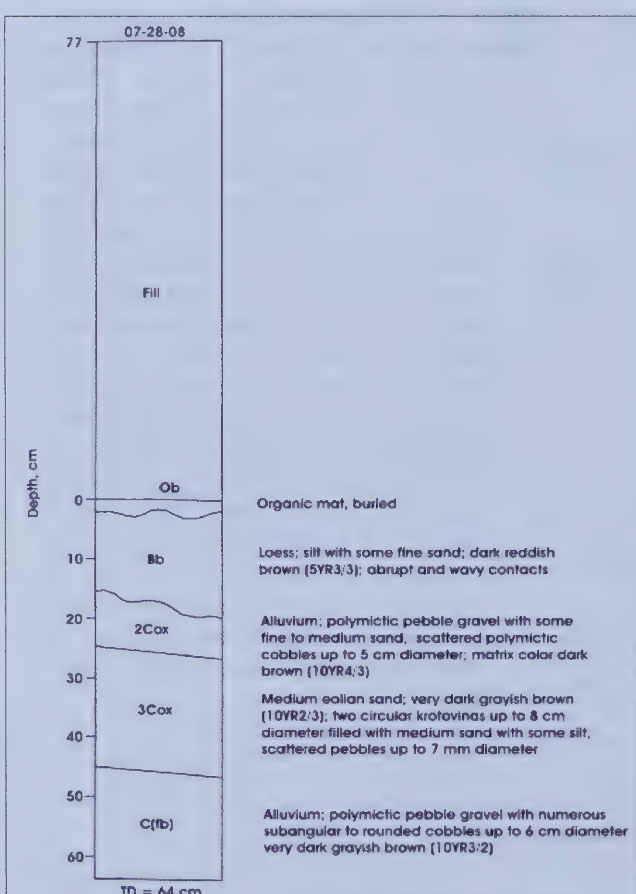


Figure 2. Course of outburst floods (blue arrows) from Mentasta Pass to Tok fan during Donnelly glaciation relative to locations of large boulders in northeastern Tok fan (localities A–C). Landforms in upper Tok River and Little River valleys interpreted from Foster (1970) and Richter (1976).



Examination of numerous gravel pits in the older, higher surface of the Tok fan indicates that this feature primarily is composed of massive pebble gravels with some medium to coarse sand, numerous cobbles, and rare boulders up to ~12 in (~30 cm) diameter. Clasts, which are generally subrounded to rounded and polymictic, generally increase in size toward the apex of the fan. In gravel exposures, Alaska Range lithologies dominate. Holmes (1965, table 4) segregated the lithologies of 100 clasts at five sites on the Tok fan into several classes: dense basalt (48–60 percent, average 54.2 percent), granitic (4–21 percent, average 12.6 percent), vesicular basalt (4–20 percent, average 10.8 percent), quartzite–quartz (3–14 percent, average 7.6 percent), andesite (0–9 percent, average 3.8 percent), gneiss–schist (0–7 percent, average 3.4 percent), and miscellaneous (3–13 percent, average 7.6 percent).

The significant percentages of volcanic lithologies in the study area are much different than in alluvial fans west of the Tok fan in the Tanana River valley and apparently represent an influx of sediment from volcanic terranes south of the Denali fault (Richter, 1976). Fernald (1965) attributed the source of volcanic erratics in the upper Tanana River drainage to the Nabesna River, a tributary of the Tanana River that drains the Wrangell Mountains. However, we traced vesicular volcanic pebbles and cobbles in gravels for several miles up the Tok River, Little Tok River, and Station Creek valleys away from the Tanana River, and believe that glaciers from the Wrangell Mountains transported volcanic clasts into the headwaters of the Tok River, where they were retransported during several glacial outburst floods as suggested by Schmoll (1984) (fig. 2). Along the Tanana River, mapping east of the Tok fan failed to identify outburst flood deposits.

MATERIAL SITE (M.S.) 62-2-005-2

Particularly instructive gravel exposures were discovered in Material Site 62-2-005-2 in an isolated remnant of the older, higher fan surface east of the Tok River (fig. 2, locality **A**). A 6-ft (1.8-m) greenstone boulder is exposed in place in clast- and matrix-supported gravels in the south pit wall (fig. 4). The bottom of the boulder is 7.9 ft (2.4 m) below the top of the gravel section in this wall. Near the center of the gravel pit, a pile of six very large boulders of granite, quartz schist, greenstone, and basalt, ranging in maximum diameter from 3.6 to 6.3 ft (1.1 to 1.9 m), provides evidence that several of these extraordinarily large rocks were encountered during pit excavation. The large in situ boulder rests in the upper part of a clean, clast-supported pebble gravel deposit with numerous subrounded to rounded polymictic cobbles and a slight pebble imbrication that indicates flow from the head of the Tok fan. Particularly noteworthy is the presence of a 4.3-in-thick (11-cm-thick) zone of disturbance beneath the boulder, perhaps indicating that the underlying material was deformed when the boulder was deposited. In this zone, pebbles are generally oriented parallel to the boulder surface; otherwise, the clast-supported gravel appears massive.

Figure 3. Soil profile (SP-11) exposed in west wall of M.S. 62-2-009-5 in western Tok fan, in west-central Tanacross B-5 Quadrangle. Elevation 1,554 ft (471 m).

The large boulder and the clast-supported gravel are abruptly overlain by matrix-supported massive pebble gravel with scattered small cobbles (fig. 4). Sieve analyses of samples S-9 and S-10 from this unit indicate that the fine fraction represents 5.4 and 2.8 weight percent, the sand fraction represents 12 and 14 weight percent, and the mean grain size is 0.86 and 0.81 in. (21.72 and 20.50 mm), respectively (table 1). Beneath the fill at the top of the wall, a layer of loess ~1.6 ft (~0.5 m) thick displays a post-Donnelly soil and is thought to be late Donnelly (MIS2) in age.

Inspection of the nearby pit walls indicates that the interbedded gravel and pebbly sand beds are generally massive, less than 3.3 ft (1 m) thick, tabular, have abrupt lower and upper contacts, and parallel the fan surface. No cross bedding is present; however, two channel fills were identified, including a 20-in-thick (50-cm-thick) lens-shaped filling of massive sand in the south wall and a ~3.3-ft-thick (~1-m-thick) channel fill of massive sand overlying clast-supported gravel in the west wall of the pit (fig. 5). Eight samples of clast- and matrix-supported gravels and pebbly sand (S-1 through S-8) were collected from the west wall of M.S. 62-2-005-2 and analyzed for grain-size distribution (fig. 6, table 1). Particularly noteworthy, although not understood, is the ubiquitous presence of vertically oriented pebbles in matrix-supported gravels at the top of the section.

Other extraordinarily large boulders were discovered at localities B and C (fig. 2). However, nowhere else in the Tok fan have these exceptionally large boulders been recovered, even in gravel pits as deep as 35 ft (10.6 m) (Glenn Burnham, 08/05/08, oral commun.), and none were present in the several deep pits we inspected.

Carter and Galloway (1978) apparently saw some of these large boulders, although likely not in place, and mapped the isolated terrace remnant as old glacial moraine (Qmo), which they correlated with moraines of the Delta glaciation (MIS 4 and 6) to the west. Foster (1970) concluded that the terrace and the older part of the Tok fan west of the Tok River are genetically related and assigned both a Delta age.

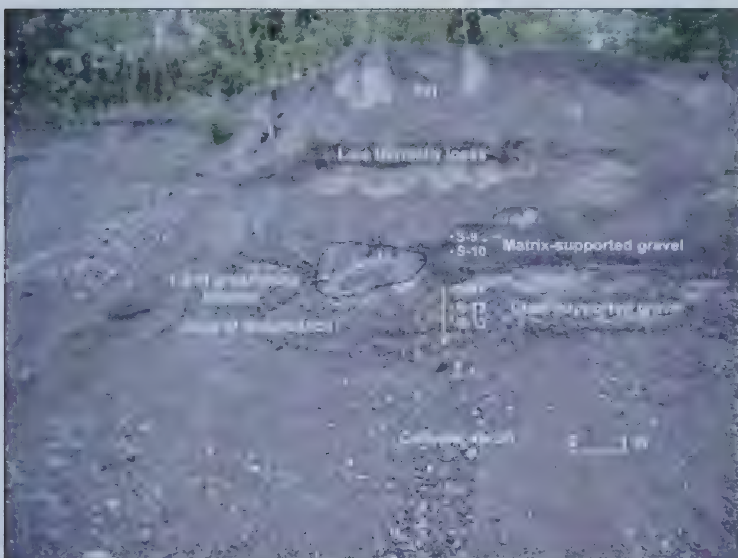


Figure 4. Extraordinarily large in situ greenstone boulder outlined for clarity in clast- and matrix-supported gravels and sample locations in south wall of M.S. 62-2-005-2, northeastern Tok fan, Tanacross B-4 Quadrangle (locality A). Photograph taken 07/29/08 by R.D. Reger.

Table 1. Grain-size distributions of gravels and sands exposed in west wall (samples S-1 through S-8) and south wall (samples S-9 through S-13) of M.S. 62-2-005-2 (locality A), Tanacross B-4 Quadrangle (figs. 4 and 6).

	Size class													
	Gravel							Sand					Fine fraction	
	Particle diameter (mm)													
Sample number	50.8	38.1	25.4	19.0	12.7	9.5	4.75	2.0	0.85	0.425	0.25	0.15	0.075	Mean diameter (mm)
S-1	---	100	94	84	73	60	38	20	13	8	5	4	2.3	6.92
S-2	---	100	97	91	82	77	58	26	10	5	3	2	1.7	3.84
S-3	---	---	100	97	93	88	71	35	8	3	2	1	1.0	2.86
S-4	100	90	88	84	80	74	57	27	12	8	5	3	2.0	3.85
S-5	100	80	69	59	46	39	29	22	19	15	12	8	5.7	14.13
S-6	100	95	85	72	57	50	34	23	18	13	9	6	3.8	9.66
S-7	---	100	87	84	78	72	55	16	4	1	1	1	0.4	4.25
S-8	---	---	100	97	94	92	76	32	7	3	2	2	1.2	2.83
S-9	100	83	55	45	32	27	21	17	15	12	9	7	5.4	21.72
S-10	100	95	62	46	38	32	23	17	13	10	7	5	2.8	20.50
S-11	100	78	55	43	32	24	13	4	2	1	1	1	0.6	22.24
S-12	100	61	46	34	28	25	18	12	8	6	5	3	1.9	27.83
S-13	100	67	59	51	41	31	18	8	4	3	2	1	0.7	18.23
	Percent passing by weight													

Figure 5. Cross section through large channel filling in west wall of M.S. 62-2-005-2, northeastern Tok fan, Tanacross B-4 Quadrangle (locality A). Contact dotted where inferred beneath colluvial apron. Geologist provides scale. Photo taken 08/01/08 by R.D. Reger.

Figure 6. Locations of samples in exposed gravels and sands in west wall of M.S. 62-2-005-2, northeastern Tok fan, Tanacross B-4 Quadrangle (locality A). Photograph taken 08/01/08 by R.D. Reger.

Carrara (2006) recognized that both surfaces are equivalent and dated them as middle Pleistocene. Based on the presence of post-Donnelly soil profiles and the generally thin cover of loess, we believe that the older part of the Tok fan surface is Donnelly (MIS 2) in age.

DISCUSSION

The lack of glacial till in any of the water wells or gravel-pit exposures in the Tok fan indicates that the extraordinarily large boulders were not deposited directly from glacial ice as inferred by Carter and Galloway (1978). The absence of stratigraphic features normally deposited by water floods, including cut-and-fill structures, ripples, and cross bedding, indicates that the boulders were not deposited by typical water floods. We propose that the very large boulder in the near-surface, tabular, clast- and matrix-supported gravels and pebbly sands in M.S. 62-2-005-2 is evidence that the extraordinarily large, rare boulders were deposited as dropstones from icebergs during massive outburst floods flowing north through the Tok River valley and spreading as waves (sheetflows) across the shallow fan surface. We speculate that these large boulders were initially dumped near the sites of their ultimate burial and then may have been rolled across the fan surface a very short distance before quickly being buried by subsequent flood pulses. Large boulders carried or moved by the flood have been found in the Tok fan only in line with the trend of the Tok River valley, indicating that the focus of the boulder-bearing outburst floods was in that direction (fig. 2, localities **B–C**). However, through time gravel-bearing flows must have traversed the fan and deposited the thick gravel layers observed.

The interlayered nature of the tabular gravels and sands enclosing the large flood boulder in M.S. 62-2-005-2 and the clear difference in their compositions (fig. 7 and table 1) indicate that the large-magnitude flows pulsated during the outburst flooding, probably as a result of temporary blockages of subglacial drainageways through which floodwaters bypassed the glacier dam (Sturm and others, 1987; Sturm and Benson, 1989; Tweed and Russell, 1999). We suggest that gravel-rich beds represent bedload components deposited by water-dominated flood pulses and that pebbly sands and matrix-supported gravels preserve components of the suspended load that were deposited by watery hyperconcentrated flows. The older part of the Tok fan has morphological characteristics, such as a broad, low gradient, low relief, and a surface network of shallow distributary channels, of a fan dominated by sheetflooding (Blair and McPherson, 1994, fig. 1B).

These massive floods had to occur many times to deliver the huge volume of coarse deposits present in the Tok fan. Inspections of several deep gravel pits indicate that at least the upper 35 ft (10.6 m) of fan sediments accumulated without a significant hiatus during the Donnelly glaciation. Deeper sediments in the Tok fan were likely laid down by pre-Donnelly outburst floods.

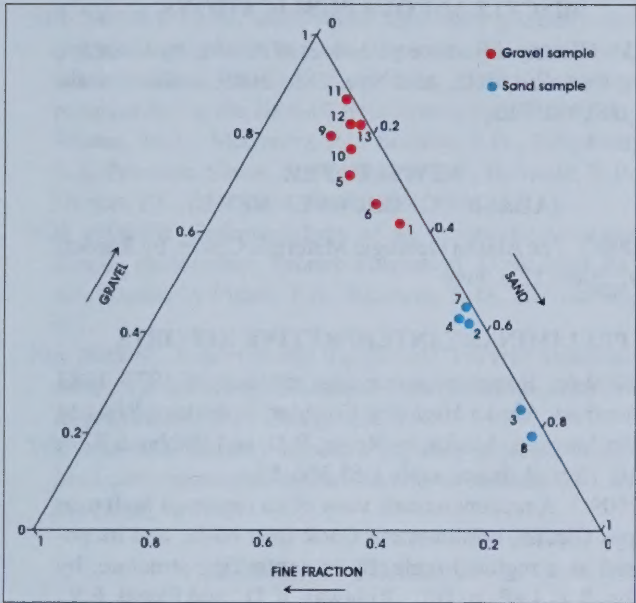


Figure 7. Abundances of gravel, sand, and fine-fraction components in samples of gravel and sand beds in south and west walls of M.S. 62-2-005-2 (table 3), northeastern Tok fan, Tanacross B-4 Quadrangle (locality A).

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Dear Readers:

In this issue of Alaska GeoSurvey News, geologists Trent Hubbard and Richard Reger report on one of the many interesting scientific outcomes from DGGS's field work along the proposed natural-gas pipeline corridor between Delta Junction and the Canada border. Their observations tell the fascinating story of multiple catastrophic glacial outburst floods that occurred in the ancestral Tok River valley during the last major glaciation. This story explains the morphology of the broad Tok fan and the presence of huge ice-rafted boulders in those gravelly deposits.

DGGS conducted its last full field season of geologic mapping and hazards evaluation along this corridor in 2009. Although there will likely be some follow-up fieldwork in 2010, our focus will shift to synthesis of all the data we've collected and preparation of final reports and maps, which will probably be ready for release in late 2011 or early 2012. DGGS initiated this effort in 2006 to evaluate the geologic hazards and resources along the Alaska Highway. This information will be useful not only for possible pipeline construction, but also for other potential future commercial and residential development along this important corridor. We no longer need to worry about catastrophic glacial outburst floods in this area, but the knowledge of these and other geologic processes helps us understand the characteristics and distribution of deposits that can serve as important sources of construction materials, as well as other potential hazards and engineering constraints.

Several significant staff changes have occurred in DGGS during the past year. Geologist John Reeder retired in June after nearly 30 years of service to DGGS and the State, the last 22 of which were as Curator of the Geologic Materials Center in Eagle River. In the fall, geologist Rocky Reifenstuhl retired after nearly 27 years of service, most of which were in the Energy Resources section. We thank both John and Rocky for their dedicated, productive service to the division. We are pleased to welcome four new geologists to the fold, as well as one returning after a short stint with another state agency. Trystan Herriott joins the Energy Resources section, Richard Koehler and Gabriel Wolken join the Engineering Geology section, Brent Elliott joins the Mineral Resources section, and returning geologist Ken Papp takes over as the new Curator of the GMC.

Finally, what about Bob? Not one to shy away from a challenge when he believes he can make a positive impact, State Geologist Bob Swenson responded to a call from Governor Sean Parnell for a temporary assignment to coordinate efforts to facilitate delivery of affordable natural gas to in-state customers. In this capacity, Bob is working closely with the Alaska Natural Gas Development Authority and former Division of Oil & Gas and U.S. Geological Survey director Mark Myers, who is coordinating development of a large-diameter pipeline to export North Slope natural gas to markets in North America and elsewhere. Bob agreed to accept this assignment on a temporary basis until October 2010, when he expects to put his DGGS hat back on and return full time to his position as state geologist. In the meantime, I am honored to again serve as acting director.

You can read more about the backgrounds of these employees as well as all of DGGS's projects in our recently released annual report. It is available either in hard copy or online at www.dggs.dnr.state.ak.us. I invite you to stop by our office or call at any time if there is any project you would like to learn more about.

Sincerely,

Rodney A Combellick

Rodney A. Combellick
Acting Director